INSTITUTION

OF

MECHANICAL ENGINEERS.

ESTABLISHED 1847.

PROCEEDINGS.

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1896.

PARTS 3–4.

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PAST-PRESIDENTS.

George Stephenson, 1847–48. (*Deceased* 1848.)

Robert Stephenson, F.R.S., 1849–53. (*Deceased* 1859.)

Sir William Fairbairn, Bart., LL.D., F.R.S., 1854–55. (*Deceased* 1874.)

Sir Joseph Whitworth, Bart., D.C.L., LL.D., F.R.S., 1856–57, 1866. (*Deceased* 1887.)

John Penn, F.R.S., 1858–59, 1867–68. (*Deceased* 1878.)

James Kennedy, 1860. (*Deceased* 1886.)

The Right Hon. Lord Armstrong, C.B., D.C.L., LL.D., F.R.S., 1861–62, 1869.

Robert Napier, 1863–65. (*Deceased* 1876.)

John Ramsbottom, 1870–71.

Sir William Siemens, D.C.L., LL.D., F.R.S., 1872–73. (*Deceased* 1883.)

Sir Frederick J. Bramwell, Bart., D.C.L., LL.D., F.R.S., 1874–75.

Thomas Hawksley, F.R.S., 1876–77. (*Deceased* 1893.)

John Robinson, 1878–79.

Edward A. Cowper, 1880–81. (*Deceased* 1893.)

Percy G. B. Westmacott, 1882–83.

Sir Lowthian Bell, Bart., F.R.S., 1884.

Jeremiah Head, 1885–86.

Sir Edward H. Carbutt, Bart., 1887–88.

Charles Cochrane, 1889.

Joseph Tomlinson, 1890–91. (*Deceased* 1894.)

William Anderson, C.B., D.C.L., F.R.S., 1892–93.

Alexander B. W. Kennedy, LL.D., F.R.S., 1894–95.

Institution of Mechanical Engineers.

OFFICERS.

1896.

PRESIDENT.

E. Windsor Richards,	Low Moor.

PAST-PRESIDENTS.

William Anderson, C.B., D.C.L., F.R.S.,	Woolwich.
The Rt. Hon. Lord Armstrong, C.B., D.C.L., LL.D., F.R.S.,	Newcastle-on-Tyne.
Sir Lowthian Bell, Bart., F.R.S.,	Northallerton.
Sir Frederick J. Bramwell, Bart., D.C.L., LL.D., F.R.S.,	London.
Sir Edward H. Carbutt, Bart.,	London.
Charles Cochrane,	Stourbridge.
Jeremiah Head,	London.
Alexander B. W. Kennedy, LL.D., F.R.S.,	London.
John Ramsbottom,	Alderley Edge.
John Robinson,	Leek.
Percy G. B. Westmacott,	Newcastle-on-Tyne.

VICE-PRESIDENTS.

Sir Douglas Galton, K.C.B., D.C.L., LL.D., F.R.S.,	London.
Samuel W. Johnson,	Derby.
Francis C. Marshall,	Newcastle-on-Tyne.
Edward P. Martin,	Dowlais.
William H. Maw,	London.
J. Hartley Wicksteed,	Leeds.

MEMBERS OF COUNCIL.

John A. F. Aspinall,	Horwich.
Henry Davey,	London.
William Dean,	Swindon.
Benjamin A. Dobson,	Bolton.
Bryan Donkin,	London.
John Hopkinson, Jun., D.Sc., F.R.S.,	London.
Arthur Keen,	Birmingham.
William Laird,	Birkenhead.
John G. Mair-Rumley,	London.
Henry D. Marshall,	Gainsborough.
Thomas Mudd,	West Hartlepool.
James Platt,	Gloucester.
T. Hurry Riches,	Cardiff.
A. Tannett Walker,	Leeds.
Sir William H. White, K.C.B., LL.D., F.R.S.,	London.

TREASURER.

Harry Lee Millar.

SECRETARY.

Alfred Bache,

Institution of Mechanical Engineers, 19 *Victoria Street*, *Westminster*, *S.W.*

[Telegraphic address:—*Mech, London.* Telephone:—*Westminster*, 264.]

Institution of Mechanical Engineers.

ESTABLISHED 1847.

LIST OF MEMBERS,

WITH YEAR OF ELECTION.

[*Telegraph Address and Telephone No. appended within brackets.*]

1896.

HONORARY LIFE MEMBERS.

1890. H. R. H. Albert Edward, Prince of Wales, K.G., K.T., K.P., G.C.B., G.C.S.I., &c., Marlborough House, Pall Mall, London, S.W.

1892. Field Marshal H.R.H. the Duke of Cambridge, K.G., K.T., K.P., G.C.B., G.C.S.I., &c., Gloucester House, Park Lane, London, W.

1883. Abel, Sir Frederick Augustus, Bart., K.C.B., D.C.L., D.Sc., F.R.S., The Imperial Institute, Imperial Institute Road, London, S.W.; and 2 Whitehall Court, London, S.W. [*Imperial Institute, London.* 8743.]

1878. Crawford and Balcarres, The Right Hon. the Earl of, K.T., F.R.S., 2 Cavendish Square, London, W.; Haigh Hall, Wigan; and Observatory, Dunecht, Aberdeen.

1889. Eiffel, Gustave, 37 Rue Pasquier, Paris.

1888. Haughton, Rev. Samuel, M.D., D.C.L., LL.D., F.R.S., Trinity College, Dublin.

1883. Kennedy, Professor Alexander Blackie William, LL.D., F.R.S., 17 Victoria Street, Westminster, S.W. [*Kinematic, London.*]

1878. Rayleigh, The Right Hon. Lord, F.R.S., 4 Carlton Gardens, London, S.W.; and Terling Place, Witham, Essex.

1888. Rosse, The Right Hon. the Earl of, K.P., D.C.L., LL.D., F.R.S., Birr Castle, Parsonstown, Ireland.

1896. Unwin, William Cawthorne, F.R.S., Professor of Engineering, City and Guilds of London Central Institution, Exhibition Road, London, S.W.; and 7 Palace Gate Mansions, Kensington, London, W.

MEMBERS.

1890. Abbott, Arthur Harold, care of Messrs. Octavius Steel and Co., Calcutta, India: (or care of F. C. Abbott, 101 Lambeth Palace Road, London, S.E.)

1878. Abbott, Thomas, Newark Boiler Works, Newark [*Abbott, Newark.*]; and Arlington House, Retford.

1883. Abbott, William Sutherland, Superintendent and Chief Engineer, Alagoas Railway, Maceio, Brazil: (or care of George S. Abbott, Lime Villa, South Woodford, Essex.)

1861. Abel, Charles Denton, Messrs. Abel and Imray, 28 Southampton Buildings, London, W.C. [*Patentable, London.* 2729.]

1874. Abernethy, James, F.R.S.E., 4 Delahay Street, Westminster, S.W.

1894. Accles, William Sloane, Redway Manufacturing Co., 44 Broadway, New York, United States.

1892. Acland, Captain Francis Edward Dyke, 76 Cheapside, London, E.C. [*Onager, London.* 15252.]

1876. Adams, Henry, 60 Queen Victoria Street, London, E.C. [*Viburnum, London.*]

1879. Adams, William, Hillrise, Amersham Road, Putney, London, S.W.

1848. Adams, William Alexander (*Life Member*), Gaines, Worcester.

1881. Adams, William John, 35 Queen Victoria Street, London, E.C. [*Packing, London.* 1854.]

1871. Adamson, Joseph, Messrs. Joseph Adamson and Co., Hyde, near Manchester. [*Adamson, Hyde.*]

1889. Addy, George, Waverley Works, Sheffield. [*Milling, Sheffield.*]

1887. Ahmed Bey, Colonel, Imperial Naval Arsenal, Constantinople.

1891. Ahrbecker, Henry Conrad Vandepoel, Morts Dock and Engineering Co., Balmain, Sydney, New South Wales.

1893. Ainley, Henry, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1886. Aisbitt, Matthew Wheldon, 47 Mount Stuart Square, Cardiff. [*Aisbitt, Cardiff.*]

1886. Albright, John Francis, Messrs. R. E. Crompton and Co., 4 Mansion House Buildings, Queen Victoria Street, London, E.C.; and 23 Michael's Grove, Brompton Road, London, S.W.

1885. Alderson, George Beeton, Messrs. Allen Alderson and Co., Alexandria, Egypt; Norland House, Ramleh, Alexandria, Egypt: (or care of Messrs. Stafford Allen and Sons, 7 Cowper Street, Finsbury, London, E.C.)

1881. Alexander, Edward Disney, Engineer's Department, London County Council; and 12 Cardigan Road, Richmond, Surrey.

1875. Allan, George, New British Iron Works, Corngreaves, near Birmingham; and Corngreaves Hall, near Birmingham.

1885. Allcard, Harry, Messrs. Easterbrook Allcard and Co., Albert Works, Penistone Road, Sheffield.

1874. Allen, Francis, Messrs. Allen Alderson and Co., Gracechurch Street, Alexandria, Egypt: (or care of Messrs. Stafford Allen and Sons, 7 Cowper Street, Finsbury, London, E.C.)

1891. Allen, Marcus, Union Brass and Iron Works, Great Ancoats Street, and Phœnix Iron Works, Jersey Street, Manchester. [*Valves*, *Manchester*. *Nat.* 60.]

1881. Allen, Percy Ruskin, Woodberrie Hill, Loughton, Essex.

1885. Allen, William Henry, Messrs. W. H. Allen Son and Co., York Street Works, Lambeth, London, S.E. [*Pump*, *London*.]; and Queen's Engineering Works, Bedford. [*Pump*, *Bedford*.]

1882. Allen, William Milward, Principal Assistant Engineer, Engine Boiler and Employers' Liability Insurance Co., 12 King Street, Manchester.

1877. Alley, Stephen, Messrs. Alley and MacLellan, Sentinel Works, Polmadie Road, Glasgow. [*Alley*, *Glasgow*. 673.]

1865. Alleyne, Sir John Gay Newton, Bart., Chevin, Belper.

1884. Alleyne, Reynold Henry Newton, 11 Avenue Victoria, Scarborough.

1872. Alliott, James Bingham, Messrs. Manlove Alliott and Co., Bloomsgrove Works, Ilkeston Road, Nottingham. [*Manloves*, *Nottingham*.]

1891. Allott, Charles Sneath, 46 Brown Street, Manchester. [*Allotted*, *Manchester*. *Nat.* 1952.]

1876. Allport, Charles James, 12 Tavistock Square, London, W.C.; and Whitehall Club, Parliament Street, Westminster, S.W.

1871. Allport, Howard Aston, Dodworth Grove, Barnsley.

1884. Almond, Harry John, General Manager, La Guaira and Caracas Railway, Caracas, Venezuela: (or care of Messrs. G. and W. Almond, 67 Willow Walk, London, S.E.)

1885. Amos, Ewart Charles, Mansion House Chambers, 11 Queen Victoria Street, London, E.C.; and Eastdene, St. James' Road, Sutton, Surrey. [*Drilling*, *London*.]

1867. Amos, James Chapman, Rose Cottage, Fairfax Road, Teddington, S.O., Middlesex.

1891. Anderson, Alexander Southerland, Chief Engineer, Ordnance Department, Ordnance Factory, Cawnpore, India.

1880. Anderson, Edward William, Messrs. Easton, Anderson and Goolden, Erith Iron Works, Erith, S.O., Kent; and Roydon Lodge, Erith, S.O., Kent.

1890. Anderson, Herbert William, Messrs. Hilton Anderson and Co., Manor Works, Halling, near Rochester.

1892. Anderson, John Wemyss, Walker Engineering Laboratories, University College, Liverpool.

1894. Anderson, Tom Scott, 59 Wilkinson Street, Sheffield.

1856. Anderson, William, C.B., D.C.L., F.R.S., Director-General of Ordnance Factories, Royal Arsenal, Woolwich; and Lesney House, Erith, S. O., Kent.

1891. Anderson, William, Messrs. Head Wrightson and Co., Teesdale Iron Works, Stockton-on-Tees.

1892. Andrew, Thomas, Rand Club, Johannesburg, Transvaal, South Africa.

1895. Andrews, Thomas, Messrs. Andrews and Baby, Welsh Wagon Works, East Moors, Cardiff. [*Wagons, Cardiff.* 693.]

1885. Anson, Frederick Henry, 15 Dean's Yard, Westminster, S.W.

1883. Appleby, Percy Vavasseur, Messrs. Jessop and Appleby Brothers, 22 Walbrook, London, E.C. [*Millwright, London.*]

1874. Aramburu y Silva, Fernando, Messrs. Aramburu and Sons, Cartridge Manufacturers, Calle de la Virgen de las Azucenas, Madrid: (or care of Manuel Cardenosa, 86 Great Tower Street, London, E.C.)

1891. Archbold, John, Eastwood Collieries, Eastwood, R.S.O., Notts.

1881. Archbold, Joseph Gibson, Manager, Blyth Dry Dock, Blyth, Northumberland.

1874. Archer, David, 275 Pershore Road, Birmingham.

1883. Arens, Henrique, Messrs. Arens and Irmaos, Engineering Works, Rio de Janeiro, Brazil: (or care of Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough.)

1882. Armer, James, Messrs. John Birch and Co., 11 Queen Street Place, London, E.C.; and The Moorings, 108 Wickham Road, Brockley, London, S.E.

1894. Armour, James Glencairn, Surveyor, Bureau Veritas, Custom House Court, Newcastle-on-Tyne.

1858. Armstrong, The Right Hon. Lord, C.B., D.C.L., LL.D., F.R.S., Elswick, Newcastle-on-Tyne; and Cragside, Morpeth.

1866. Armstrong, George, Locomotive Department, Great Western Railway, Stafford Road Works, Wolverhampton.

1882. Armstrong, George Frederick, F.R.S.E., Professor of Engineering, The University, Edinburgh.

1876. Armstrong, William, Jun., Mining Engineer, Wingate Colliery, County Durham.

1870. Armstrong, William Irving, Timber Works and Saw Mills, 17 North Bridge Street, Sunderland.

1894. Arnot, William, Glasgow Corporation Electric Lighting Station, 75 Waterloo Street, Glasgow. [*Induction, Glasgow.* 4665.]

1887. Arrol, Sir William, M.P., LL.D., Dalmarnock Iron Works, Glasgow.

1887. Arteaga, Alberto de, 1320 Artes, Buenos Aires, Argentine Republic: (or care of M. Raggio-Carneiro, 129A Winchester House, Old Broad Street, London, E.C.)

1873. Ashbury, Thomas (*Life Member*), 5 Market Street, Manchester; and Ash Grove, Victoria Park, Longsight, Manchester. [*Thomas Ashbury, Manchester.*]

1888. Ashby, George, Tardeo, Bombay, India.

1895. Ashcroft, Andrew George, Principal, Woolwich Polytechnic, William Street, Woolwich; and 6 St. Margaret's Road, Plumstead.

1890. Ashley, Thomas James, Messrs. Fawcett Preston and Co., Phœnix Foundry, Liverpool.

1884. Ashwell, Frank, Messrs. Ashwell and Nesbit, Victoria Foundry, Sycamore Lane, Leicester. [*Iron, Leicester.* 100.]

1891. Ashworth, Henry, The Villa, Llangorse, Talgarth, R.S.O., Breconshire.

1890. Askham, John Unwin, Messrs. Askham Brothers and Wilson, Yorkshire Steel Works, Napier Street, Sheffield.

1890. Askham, Philip Unwin, Messrs. Askham Brothers and Wilson, Yorkshire Steel Works, Napier Street, Sheffield.

1881. Aspinall, John Audley Frederick, Chief Mechanical Engineer, Lancashire and Yorkshire Railway, Horwich, near Bolton; and Fern Bank, Heaton, Bolton.

1891. Asplen, Bernard, Southall: (or care of W. W. Asplen, Foxton Hall, Royston, Cambridgeshire.)

1877. Astbury, James, Smethwick Foundry, near Birmingham.

1890. Aston, John W., Messrs. G. E. Belliss and Co., Ledsam Street, Birmingham; and Municipal Technical School, Birmingham.

1889. Atkinson, Alexander, Jammu, Kashmir, India: (or care of Messrs. Grindlay and Co., 55 Parliament Street, Westminster, S.W.)

1875. Atkinson, Edward (*Life Member*), 32 Park Road, West Dulwich, London, S.E.

1890. Atkinson, Edward Turner, London County Council, Spring Gardens, London, S.W.

1892. Atkinson, James, The Woodlands, Marple, near Stockport.

1892. Ault, Edwin, 47 Victoria Street, Westminster, S.W.

1892. Austin, James Meredith, Messrs. R. E. Crompton and Co., Arc Works, Chelmsford; and 2 Prospect Terrace, Springfield, Chelmsford.

1882. Aveling, Thomas Lake, Messrs. Aveling and Porter, Rochester. [*Aveling, Rochester.*]

1891. Bagshaw, Walter, Victoria Foundry, Batley.

1885. Bailey, Sir William Henry, Albion Works, Salford, Manchester [*Beacon, Salford.*]; and Sale Hall, Cheshire.

1872. Bailly, Philimond, 282 Rue Royale, Bruxelles, Belgium.

1890. Bain, George, Locomotive Department, Egyptian Government Railways, Cairo, Egypt.

1880. Bain, William Neish, 40 St. Enoch Square, Glasgow; and Collingwood, 7 Aytoun Road, Pollokshields, Glasgow. [*Glacis, Glasgow.*]

1869. Bainbridge, Emerson, M.P., Nunnery Colliery Offices, New Haymarket, Sheffield.

1873. Baird, George, St. Petersburg; and Fulmer, Slough.

1890. Baker, Sir Benjamin, K.C.M.G., LL.D., F.R.S. (*Life Member*), 2 Queen Square Place, Westminster, S.W.

1896. Baker, William Henry, Superintendent of Works, Residency Post Office, Gwalior, Central India.

1875. Bakewell, Herbert James, Engineer, Department of the Controller of the Navy, Admiralty, Whitehall, London, S.W.

1893. Baldwin, Alfred, M.P., Wilden Iron Works, Stourport.

1894. Baldwin, Arthur Hugh, Messrs. Kendall and Gent, Victoria Works, Springfield, Salford, Manchester. [*Tools, Manchester.* Nat. 330; Mutual 1330.]

1877. Bale, Manfred Powis, Appold Street, Finsbury, London, E.C.

1884. Balmokand, Rai Bahadur, Executive Engineer, 4th Division, Chenab Canal, Lahore, Punjaub, India.

1887. Bamlett, Adam Carlisle, Agricultural Engineering Works, Thirsk.

1892. Banister, George Henry, Carriage Department, Royal Arsenal, Woolwich.

1888. Barker, Eric Gordon, Locomotive Superintendent, Wirral Railway, Dock Station, Birkenhead; and Guyse House, Oxton, R.O., near Birkenhead.

1896. Barker, Matthew Wilson, P.O. Box 1463, Johannesburg, Transvaal, South Africa.

1885. Barker, Tom Birkett, Scholefield Street, Birmingham. [*Gasengine, Birmingham.* 2530.]

1880. Barlow-Massicks, Thomas, The Oaks, Millom, Cumberland.

1891. Barnes, John Edward Lloyd, Messrs. Sloan and Lloyd Barnes, Castle Chambers, 26 Castle Street, Liverpool. [*Technical, Liverpool.*]

1881. Barnett, John Davis, Assistant Mechanical Superintendent, Grand Trunk Railway, Stratford, Ontario, Canada.

1887. Barningham, James, 41 Victoria Buildings, Victoria Street, Manchester.

1884. Barr, Archibald, D.Sc., Professor of Engineering, The University, Glasgow.

1882. Barrett, John James, 5 Chinchpoogly Road, Bombay, India.

1885. Barrie, William, Superintendent Engineer, Nippon Yusen Kaisha Steam Ship Co., 266 Bluff, Yokohama, Japan.

1887. Barringer, Herbert, 88 Bishopsgate Street Within, London, E.C.

1862. Barrow, Joseph, Messrs. Thomas Shanks and Co., Johnstone, near Glasgow. [*Shanks, Johnstone.*]

1871. Barry, John Wolfe, C.B., F.R.S., 21 Delahay Street, Westminster, S.W. [*Consilium, London.* 3024.]

1883. Bartlett, James Herbert, Middlesbrough, Kentucky, United States.

1887. Bate, Major Charles McGuire, R.E., Royal Engineers' Office, Mauritius.

1885. Bateman, Henry, Superintendent, Municipal Fire Brigade and Stores, Rangoon, India.

1896. Bateman, James Thomas, Messrs. Lever Brothers, Sunlight Soap Works, Birkenhead; and Fair View, Bebington, near Birkenhead.

1891. Bates, Henry, Messrs. Hulse and Co., Ordsal Works, Regent Bridge, Salford, Manchester; and 30 Halliwell Terrace, Trafford Road, Salford, Manchester.

1892. Baxter, Peter Macleod, Messrs. McKie and Baxter, Copland Works, Govan, Glasgow.

1889. Bayford, William James, Engineer and Manager, Messrs. Meakin and Co., Brewers, Delhi, India.

1872. Bayliss, Thomas Richard, Belmont, Northfield, Birmingham.

1891. Baynes, John, Midland Railway-Carriage and Wagon Co., Suffolk House, Laurence Pountney Hill, London, E.C.

1877. Beale, William Phipson, Q.C., 10 New Court, Carey Street, London, W.C.; and 19 Upper Phillimore Gardens, Kensington, London, W.

1895. Beard, Bernard, Messrs. Francis Morton and Co., Hamilton Iron Works, Garston, near Liverpool.

1887. Beardmore, William, Parkhead Forge and Steel Works, Glasgow.

1893. Beare, Thomas Hudson, F.R.S.E., Professor of Engineering, University College, Gower Street, London, W.C.

1893. Beastow, William Henry, Messrs. Brooks and Doxey, Union Iron Works, West Gorton, Manchester; and Junction Iron Works, Miles Platting, Manchester; and 157 Hyde Road, West Gorton, Manchester.

1891. Beatty, Hazlitt Michael, Chief Locomotive Superintendent, Cape Government Railways, Cape Town, Cape Colony; and Rosclare Camp Ground, Rondebosch, near Cape Town, Cape Colony.

1880. Beaumont, William Worby, Outer Temple, 222 Strand, London, W.C. [*Vibromotor, London.*]

1859. Beck, Edward (*Life Member*), Dallam Forge, Warrington; and Springfield, Warrington.

1873. Beck, William Henry, 115 Cannon Street, London, E.C.

1887. Beckwith, George, 313 Hainault Road, Leytonstone, London, N.E.

1875. Beckwith, John Henry, Managing Director, Messrs. Galloways, Knott Mill Iron Works, Manchester.

1882. Bedson, Joseph Phillips, Parkhurst, Middlesbrough.

1875. Beeley, Thomas, Engineer and Boiler Maker, Hyde Junction Iron Works, Hyde, near Manchester. [*Beeley, Hyde.*]

1888. Beldam, Asplan, 77 Gracechurch Street, London, E.C.

1885. Bell, Charles Lowthian, Clarence Iron Works, Middlesbrough; and Linthorpe, Middlesbrough. [*Bells, Middlesbrough.* 5510.]

1858. Bell, Sir Lowthian, Bart., F.R.S., Clarence Iron Works, Middlesbrough; Rounton Grange, Northallerton; and Reform Club, Pall Mall, London, S.W. [*Sir Lowthian Bell, Middlesbrough.*]

1868. Belliss, George Edward, Steam Engine and Boiler Works, Ledsam Street, Birmingham [*Belliss, Birmingham.*]; and The Dell, King's Norton, near Birmingham.

1878. Belsham, Maurice, Messrs. Price and Belsham, 52 Queen Victoria Street, London, E.C.

1880. Benham, Percy, Messrs. Benham, 66 Wigmore Street, London, W. [*Benham, London.* 7065.]

1895. Benn, Sykes, Messrs. S. S. Stott and Co., Haslingden, near Manchester. [*Elevator, Haslingden.* 103.]

1894. Bennett, James William, Messrs. Taylor and Lawson, Engineering Works, Batavia; and Alington, Dean Park, Bournemouth.

1895. Bennington, John William, Staff Engineer, H.M.S. "Hermione," Particular Service Squadron.

1895. Bennion, Charles, Messrs. Pearson and Bennion, Union Works, Leicester; and Danes Hill House, Hinckley Road, Leicester. [*Prominent, Leicester.* 103.]

1894. Bentley, George, Messrs. Bentley and Jackson, Lodge Bank Works, Bury, Lancashire.

1895. Berchem, Alphonse Henry Emanuel, Worthington Pumping Engine Co., 153 Queen Victoria Street, London, E.C.

1890. Berkley, James Eustace, Consulting Engineer, Bombay, India.

1878. Berrier-Fontaine, Marc, Directeur des Constructions navales, Directeur de l'Établissement national d'Indret, par la Basse Indre, (Loire inférieure), France.

1893. Berry, Henry, Croydon Works, Leeds.

1893. Berry, John Ferrier, care of Messrs. Howard Farrar and Co., P. O. Box 455, Johannesburg, Transvaal, South Africa.

1890. Bertram, Alexander, Messrs. Newton Chambers and Co., Thorncliffe Iron Works and Collieries, near Sheffield.

1891. Bertram, David Noble, Messrs. Bertrams, St. Katherine's Works, Sciennes, Edinburgh.

1861. Bessemer, Sir Henry, F.R.S., Denmark Hill, London, S.E.

1891. Best, Francis Edward, 1 Swan Walk, Chelsea Embankment, London, S.W.

1893. Betts, Samuel, Locomotive Superintendent, Oxelösund-Fleu-Westmanlands Railway, Eskilstuna, Sweden.

1891. Bevis, Alfred William, Brunswick Villa, Malvern Road, Acock's Green, Birmingham.

1866. Bevis, Restel Ratsey, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead; and Manor Hill, Birkenhead.

1892. Bickle, Thomas Edwin, Messrs. Bickle and Co., Great Western Docks, Plymouth. [*Engineers, Plymouth.* 176.]

1885. Bicknell, Arthur Channing, 42 Pelham Street, South Kensington, London, S.W.

1883. Bicknell, Edward, 17 Russell Street, Bath.

1884. Bika, Léon Joseph, Locomotive Engineer-in-Chief, Belgian State Railway, 29 Rue des Palais, Bruxelles, Belgium.

1888. Billinton, Robert John, Locomotive Superintendent, London Brighton and South Coast Railway, Brighton.

1890. Bingham, Charles Henry, Messrs. Walker and Hall, Electro Works, Howard Street, Sheffield. [*Bingham, Sheffield.*]

1887. Binnie, Alexander Richardson, Engineer, London County Council, Spring Gardens, London, S.W.; and 77 Ladbroke Grove, Notting Hill, London, W.

1877. Birch, Robert William Peregrine, 5 Queen Anne's Gate, Westminster, S.W.

1891. Bird, George, Messrs. James Bartle and Co., Western Iron Works, Notting Hill, London, W.

1880. Birkett, Herbert, 91 Victoria Street, Westminster, S.W.

1896. Black, Peter Blair, 185 Palmerston Buildings, Old Broad Street, London, E.C. [*Blackness, London.*]

1879. Black, William, 1 Lovaine Place, Newcastle-on-Tyne.

1891. Black, William, Eaglescliffe, Newport Road, Cardiff.

1891. Blackburn, Arthur Henry, Fuel Economizer Co., Matteawan, New York, United States.

1891. Blackburn, George William, Messrs. T. Green and Son, Smithfield Iron Works, Leeds.

1890. Blackburn, John, Resident Engineer, Colne Valley Water Works, Bushey, Watford.

1862. Blake, Henry Wollaston, F.R.S., 8 Devonshire Place, London, W.

1886. Blandford, Thomas, Corbridge, R.S.O., Northumberland.

1881. Blechynden, Alfred, Messrs. John Penn and Sons, Greenwich, London, S.E.

1892. Blechynden, John, General Manager, Shanghai Engineering, Shipbuilding and Dock Company, Shanghai, China. [*Steam, Shanghai.*]

1867. Bleckly, John James, Bewsey Iron Works, Warrington; and Daresbury Lodge, Altrincham.

1882. Blundstone, Samuel Richardson, Catherine Chambers, 8 Catherine Street, Strand, London, W.C.

1884. Bocquet, Harry Claude, Llanwye, Hampton Park, Hereford.

1863. Boeddinghaus, Julius, Electrotechniker, Düsseldorf, Germany.

1895. Bond, George Creswell, Newcastle Chambers, Nottingham. [*Bonds, Nottingham.* 441.]

1884. Bone, William Lockhart, Works of the Ant and Bee, West Gorton, Manchester.

1895. Boorman, Joseph Ashworth, Messrs. Greenwood and Batley, Albion Works, Leeds.

1892. Booth, John William, Union Foundry, Rodley, near Leeds.

1890. Booth, Robert, Messrs. Booth and Ravenshaw, 110 Cannon Street, London, E.C.

1880. Borodin, Alexander, President, Ribinsk Railway; Demidoff pereoulok, 1, St. Petersburg, Russia.

1888. Borrows, William, Messrs. Edward Borrows and Sons, Providence Foundry, Sutton, St. Helen's, Lancashire.

1891. Boswell, Samuel, Messrs. Galloways, Branch Works, Ardwick, Manchester.

1888. Boulding, Sidney, Messrs. Green and Boulding, 21 Featherstone Street, London, E.C. [*Temperature, London.*]

1886. Boult, Alfred Julius, Messrs. Boult and Wade, 111 Hatton Garden, London, E.C. [*Boult, London.* 2896.]

1878. Bourdon, François Edouard, 74 Faubourg du Temple, Paris: (or care of Messrs. Negretti and Zambra, Holborn Viaduct, London, E.C.)

1886. Bourne, Thomas Johnstone, Imperial Chinese Railways, Tientsin, China: (or care of Mrs. Bourne, 16 Park Road, Southborough, Tunbridge Wells.)

1879. Bourne, William Temple, Messrs. Bourne and Grove, Bridge Steam Saw Mills, Worcester.

1891. Bousfield, John Ebenezer, 4 South Street, Finsbury, London, E.C. [*Invention, London.* 169.]

1879. Bovey, Henry Taylor, LL.D., Professor of Engineering, McGill University, Montreal, Canada.

1880. Bow, William, Messrs. Bow McLachlan and Co., Thistle Engine Works, Paisley. [*Bow, Paisley.*]

1888. Bowen, Edward (*Life Member*), Locomotive and Carriage Superintendent, Porto Alegre and New Hamburg Railway, Rio Grande do Sol, Brazil: (or care of Benjamin Packham, 18 Upper Wellington Road, Brighton.)

1858. Bower, John Wilkes (*Life Member*), Meredale, Rugby Road, Leamington Spa.

1892. Bowker, Arthur F., Engineer, Mid-Kent Water Works, Snodland, S.O., Kent.

1893. Boyd, James Tennant, Boyd's Ice Factory, Bombay, India.

1890. Boyd, John White, 6 Oswald Street, Glasgow. [*Silent, Glasgow.*]

1884. Boyer, Robert Skeffington, 46 Mount Stuart Square, Cardiff.

1882. Bradley, Frederic, Sandhills, Liverpool; Clensmore Foundry, Kidderminster; and Wolverley House, Southport.

1896. Bradney, Walter, Billiter Buildings, Billiter Street, London, E.C.

1878. Braithwaite, Charles C., Boreham Wood Works, Elstree, Herts. [*Packing, Boreham Wood.*]

1875. Braithwaite, Richard Charles, Messrs. Braithwaite and Kirk, Crown Bridge Works, Westbromwich [*Braithwaite, Westbromwich.*]; and 39 Victoria Street, Westminster, S.W.

1854. Bramwell, Sir Frederick Joseph, Bart., D.C.L., LL.D., F.R.S., Messrs. Bramwell and Harris, 5 Great George Street, Westminster, S.W. [*Wellbram, London.* 3060.]

1892. Brand, David Jollie, Messrs. Brand and Dryburgh, Cleveland Foundry and Engine Works, Townsville, North Queensland.

1888. Bratt, Augustus Hicks Henery, Le Kueh Coal and Iron Mines, Kiangsu, North China; Astor House, Shanghai, China: (or care of Messrs. J. H. Bower and Co., 138 Leadenhall Street, London, E.C.) [*Bratt, Shanghai.*]

1895. Bratt, Edward Hicks Fraser, Messrs. Bratt and Gibson, Taiping, Perak, Straits Settlements.

1885. Brearley, Benjamin J., Union Plate Glass Works, St. Helen's; and The Laurels, Queen's Park, St. Helen's.

1891. Brewster, Edwin Henry George, 12 Delahay Street, Westminster, S.W.

1890. Brewster, Walter Seckford, Messrs. Beyer Peacock and Co.; Wrentham, Fleet Street, Carlton, near Sydney, New South Wales.

1887. Brier, Henry, Messrs. J. H. Carruthers and Co., Hamilton Street, Polmadie, Glasgow.

1889. Briggs, Charles, care of Robert Briggs, Howden.

1881. Briggs, John Henry, Babcock and Wilcox Boiler Works, Renfrew.

1894. Brindley, George Samuel, Cliffe House, Smethwick, near Birmingham.

1895. Britten, Thomas Johnson, P.O. Box 494, Johannesburg, Transvaal, South Africa.

1891. Broadbent, William, Messrs. Thomas Broadbent and Sons, Central Iron Works, Huddersfield. [*Broadbent, Huddersfield.* 102.]

1896. Broadfoot, Andrew Wilson, Locomotive Superintendent, Great Southern Railway, Albany, Western Australia.

1891. Brock, Cameron William Harrison, care of Roxburghe Press, 15 Victoria Street, Westminster, S.W.

1865. Brock, Walter, Messrs. Denny and Co., Engine Works, Dumbarton. [*Lennox, Dumbarton.* 1 and 15.]

1896. Brocklehurst, George, Bridgetown, Barbados, West Indies.

1890. Brodie, John Alexander, 3 Cook Street, Liverpool.

1852. Brogden, Henry (*Life Member*), Hale Lodge, Altrincham, near Manchester.

1890. Brogden, Thomas, Messrs. Appleby and Brogden, Sandside, Scarborough.

1892. Bromiley, William J., Messrs. Dobson and Barlow, Kay Street Machine Works, Bolton.

1892. Brooke, John Walter, Adrian Iron Works, Lowestoft.

1892. Brooke, Robert Grundy, Messrs. Holden and Brooke, St. Simon's Works, Salford, Manchester. [*Influx, Manchester.*]

1884. Brook-Fox, Frederick George, care of Messrs. Grindlay, Groom and Co., Bombay, India.

1880. Brophy, Michael Mary, Messrs. James Slater and Co., 251 High Holborn, London, W.C.

1874. Brotherhood, Peter, 15 and 17 Belvedere Road, Lambeth, London, S.E.; and 15 Hyde Park Gardens, London, W. [*Brotherhood, London.*]

1886. Brown, Andrew, 110 Cannon Street, London, E.C.; and Willis Road, Erith, S.O., Kent.

1866. Brown, Andrew Betts, F.R.S.E., Messrs. Brown Brothers and Co., Rosebank Iron Works, Edinburgh.

1891. Brown, Arthur Mogg, P.O. Box 491, Johannesburg, Transvaal, South Africa.

1885. Brown, Benjamin, Widnes Foundry, Widnes.

1880. Brown, Francis Robert Fountaine, Mechanical Superintendent, Intercolonial Railway of Canada, Moncton, New Brunswick, Canada.

1889. Brown, Lieutenant Frederick Alexander William, R.A., Inspector of Ordnance Machinery, The Castle, Cape Town, Cape Colony: (or 42 Fermoy Road, St. Peter's Park, London, W.)

1881. Brown, George William, Messrs. Huntley Boorne and Stevens, Reading Tin Works, Reading. [251.]

1892. Brown, James Fiddes, 147 Woodbridge Road, Ipswich.

1884. Brown, Oswald, 32 Victoria Street, Westminster, S.W. [*Acqua, London.*]

1888. Brown, William, Messrs. W. Simons and Co., London Works, Renfrew.

1892. Brown, William, Messrs. Siemens Brothers and Co., Woolwich.

1874. Browne, Tomyns Reginald, Deputy Locomotive Superintendent, East Indian Railway, Jamalpur, Bengal, India: (or care of Mrs. Browne, care of A. C. Brett, Mozufferpore, East Liss, Hants.)

1874. Bruce, Sir George Barclay, 3 Victoria Street, Westminster, S.W.

1889. Bruce, Robert, 30 Great St. Helen's, London, E.C. [*Tangential, London.*]

1867. Bruce, William Duff, 17 Victoria Street, Westminster, S.W.; and 23 Roland Gardens, South Kensington, London, S.W.

1888. Bruff, Charles Clarke, Coalport China Co., Coalport, near Ironbridge, Salop.

1873. Brunel, Henry Marc, 21 Delahay Street, Westminster, S.W. [3024.]

1892. Brunlees, John, 12 Victoria Street, Westminster, S.W. [3245.]

1887. Brunton, Philip George, Resident Engineer, Department of Roads and Bridges, Public Works Office, Sydney, New South Wales: (or care of J. D. Brunton, 19 Great George Street, Westminster, S.W.)

1884. Bryan, William B., Engineer, East London Water Works, Lea Bridge, Clapton, London, N.E.

1892. Buckley, John T., Messrs. Stevenson and Co., Canal Foundry, Preston; and 50 Poulton Street, Kirkham, near Preston.

1877. Buckley, Samuel, Messrs. Buckley and Taylor, Castle Iron Works, Oldham.

1895. Buckley, Victor Emanuel, Managing Director, Riga Spinning and Thread Works, Strasdenhof, Riga, Russia.

1886. Buckney, Thomas, Messrs. E. Dent and Co., 61 Strand, London, W.C.

1887. Buckton, Walter, 27 Ladbroke Square, London, W.

1896. Buckwell, George William, Board of Trade Offices, Custom House Arcade, Liverpool.

1878. Buddicom, Harry William, Penbedw, Nannerch, near Mold.

1886. Budenberg, Christian Frederick, Messrs. Schäffer and Budenberg, Whitworth Street, London Road, Manchester; and Bowden Lane, Marple, Stockport. [*Manometer, Manchester.* 899.].

1882. Budge, Enrique, Engineer-in-Chief, Harbour Works, Valparaiso, Chile: (or care of Messrs. Rose-Innes Cox and Co., 4 Fenchurch Avenue, London, E.C.)

1881. Bulkley, Henry Wheeler, N.Y. Times Building, 41 Park Row, New York, United States.

1884. Bullock, Joseph Howell, General Manager, Pelsall Coal and Iron Works, near Walsall; and Glenhurst, Lichfield Road, Walsall.

1882. Bulmer, John, Spring Garden Engineering Works, Pitt Street, Newcastle-on-Tyne.

1891. Bumsted, Francis Dixon, Cannock Chase Foundry and Engine Works, Hednesford, near Stafford.

1884. Bunt, Thomas, Superintendent Engineer, Kiangnan Arsenal, Shanghai, China: (or care of R. Pearce, Lanarth House, Holders Hill, Hendon, London, N.W.)

1884. Bunting, George Albert, Locomotive Superintendent, Estrada de Ferro Recife e São Francisco, Pernambuco, Brazil.

1885. Burder, Walter Chapman, Messrs. Messenger and Co., Loughborough.

1891. Burgess, Francis Chassereau Boughey, Office of Director General of Railways, Technical Section, Simla, India.

1894. Burke, Michael James, Locomotive and Carriage Superintendent, Morvi Railway, Morvi, India.

1881. Burn, Robert Scott, Oak Lea, Edgeley Road, near Stockport.

1893. Burnes, Thomas, Fleet Engineer, R.N., H.M.S. "Ajax," Chatham.

1878. Burnett, Robert Harvey, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1878. Burrell, Charles, Jun., Messrs. Charles Burrell and Sons, St. Nicholas Works, Thetford. [*Burrell, Thetford.*]

1885. Burrell, Frederick John, Messrs. Charles Burrell and Sons, St. Nicholas Works, Thetford. [*Burrell, Thetford.*]

1887. Burstal, Edward Kynaston, Messrs. Stevenson and Burstal, 38 Parliament Street, Westminster, S.W.

1896. Burstall, Frederic William, Professor of Engineering, Mason Science College, Birmingham.

1890. Burstall, Henry Robert John, 14 Old Queen Street, Westminster, S.W.

1884. Butcher, Joseph John, P. O. Box 132, Thompsonville, Connecticut, United States.

1882. Butler, Edmund, Kirkstall Forge, near Leeds. [*Forge, Kirkstall.*]

1892. Butler, Henry William, care of F. B. Behr, 6 Old Jewry, London, E.C.

1884. Butler, Hugh Myddleton, Kirkstall Forge, near Leeds.

1891. Butler, James, Victoria Iron Works, Halifax; and Longfield, Halifax.

1888. Butter, Frederick Henry, Carriage Department, Royal Arsenal, Woolwich; and 41 Montpelier Vale, Blackheath, London, S.E.

1891. Butter, Henry Joseph, Messrs. Tannett Walker and Co., Leeds; and Claremont, Burrage Road, Plumstead.

1894. Butterworth, Joseph, Messrs. Lancaster and Tonge, Pendleton, Manchester.

1892. Byrne, Francis Furlong, Engineer, Harbour Office, Drogheda, Ireland. [*Byrne, Engineer, Drogheda.*]

1887. Caiger, Emery John, Messrs. E. J. Caiger and Co., 77 Billiter Buildings, Billiter Street, London, E.C. [*Caiger, London.*]

1886. Cairnes, Frederick Evelyn, Bridgewater Hotel, Worsley, near Manchester.

1889. Callan, William, River Plate Fresh Meat Co., 2 Coleman Street, London, E.C.

1886. Cambridge, Henry, Stuart Chambers, Mount Stuart Square, Cardiff.

1893. Campbell, Andrew Chisholm, Messrs. James Campbell and Sons, Vulcan Engine Works, William Moult Street, Liverpool.

1877. Campbell, Angus, Logie, Mussoorie, N. W. Provinces, India.

1880. Campbell, Daniel, Messrs. Campbell, Macmaster and Co., 11 and 12 Clement's Lane, Lombard Street, London, E.C. [*Duke, London.* 2011.]

1869. Campbell, James, Hunslet Engine Works, Leeds. [*Engineco, Leeds.*]

1893. Campbell, James Alexander Miller, Messrs. James Campbell and Sons, Vulcan Engine Works, William Moult Street, Liverpool.

1882. Campbell, John, Messrs. R. W. Deacon and Co., Kalimaas Works, Soerabaya, Java.

1892. Campbell, William Walker, Messrs. Campbell and Calderwood, Soho Engine Works, Paisley. [*Soho, Paisley.* 162.]

1885. Capito, Charles Alfred Adolph, Rushbourne, Ramsgate; and 13 Victoria Street, Westminster, S.W.

1892. Capper, David Sing, Professor of Mechanical Engineering, King's College, Strand, London, W.C.

1860. Carbutt, Sir Edward Hamer, Bart., 19 Hyde Park Gardens, London, W.; and Nanhurst, Cranleigh, Guildford.

1878. Cardew, Cornelius Edward, Locomotive and Carriage Superintendent, Burma State Railways, Insein, Burma; care of Messrs. H. S. King and Co., 65 Cornhill, London, E.C.: (or care of Rev. J. H. Cardew, Wingfield Rectory, Trowbridge.)

1875. Cardozo, Francisco Corrêa de Mesquita (*Life Member*), Messrs. Cardozo and Irmâo, Pernambuco Engine Works, Pernambuco, Brazil: (or care of Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.)

1892. Carnegie, David, Royal Laboratory, Royal Arsenal, Woolwich.

1866. Carpmael, William, 24 Southampton Buildings, London, W.C. [*Carpmael, London.* 2608.]

1877. Carr, Robert, 1 West Pier, London Docks, London, E.

1895. Carr, Robert Alfred, 1 West Pier, London Docks, London, E.

1892. Carrack, Charles, Messrs. Crossley Brothers, 116 New Street, Birmingham.

1884. Carrick, Henry, Messrs. Carrick and Wardale, Redheugh Engine Works, Gateshead; and Hall Garth, Coatham Mundeville, Darlington. [*Wardale, Gateshead.*]

1885. Carter, Herbert Fuller, Calle de Gante 11, Ciudad de Mexico, Mexico: (or care of H. Maynard Carter, 79 Wool Exchange, Coleman Street, London, E.C.)

1877. Carter, William, Manager, The Hydraulic Engineering Company, Chester.

1888. Castle, Frank, Royal College of Science, Exhibition Road, South Kensington, London, S.W.

1891. Caswell, Samuel John, 31 Sakai Machi, Kobe, Japan.

1892. Causer, William George, Brighton Villa, Handsworth, R.O., Birmingham.

1883. Cawley, George, 29 Great George Street, Westminster, S.W.

1892. Chadwick, Osbert, C. M. G., Crown Agents' Department, Colonial Office, Downing Street, London, S.W.; and 11 Airlie Gardens, Kensington, London, W.

1894. Chaffey, George, P.O. Box 75, Mildura, Victoria.

1876. Challen, Stephen William, Messrs. Taylor and Challen, Derwent Foundry, 60 and 62 Constitution Hill, Birmingham. [*Derwent, Birmingham.*]

1892. Chalmers, George, St. John del Rey Mining Co., 28 Tower Chambers, Finsbury Pavement, London, E.C.

1886. Chalmers, John Reid, 18 Hemingford Road, Barnsbury, London, N.

1896. Chambers, Robert Martin, Messrs. Chambers and Co., Cuba Street, Belfast.

1890. Chandler, Noel, Cannock Chase Foundry and Engine Works, Hednesford, near Stafford.

1887. Chapman, Alfred Crawhall, 3 St. Nicholas' Buildings, Newcastle-on-Tyne.

1888. Chapman, Arthur, Assam Railways and Trading Co., 1 Clive Ghat Street, Calcutta, India; The New Club, Calcutta, India: (or St. Andrew's Cottage, Bury St. Edmund's.)

1866. Chapman, Henry, 69 Victoria Street, Westminster, S.W. [*Tubalcain, London.*]; and 10 Rue Laffitte, Paris.

1878. Chapman, James Gregson, Messrs. Fawcett Preston and Co., Phœnix Foundry, Liverpool; and 25 Austinfriars, London, E.C. [*Fawcett, London.*]

1887. Chapman, Joseph Crawhall, 70 Chancery Lane, London, W.C.; and St. Mildred's, Lovelace Gardens, Surbiton.

1893. Charlesworth, Sheard, Messrs. S. Charlesworth and Co., Richmond Hill Iron Works, Oldham. [*Charlesworth, Engineers, Oldham.* 63.]

1885. Charnock, George Frederick, Engineering Department, Technical College, Bradford.

1895. Charnock, James (*Life Member*), Messrs. Vikoul Morosoff and Sons, Orehovo, near Moscow, Russia: (or care of Messrs. Samuel Montagu and Co., 60 Old Broad Street, London, E.C.)

1877. Chater, John, Messrs. Henry Pooley and Son, 89 Fleet Street, London, E.C.

1890. Chater, John Richard, Messrs. Henry Pooley and Son, Albion Foundry, Harecastle Junction, Staffordshire.

1885. Chatfeild Clarke, Leslie, 132 Westbourne Terrace, Hyde Park, London, W.

1891. Chatterton, Alfred, Professor of Engineering, College of Engineering, Madras, India; and 10 Mundania Road, Honor Oak, London, S.E.

1887. Chatwin, James, Victoria Works, Great Tindal Street, Ladywood, Birmingham.

1867. Chatwood, Samuel, Lancashire Safe and Lock Works, Bolton; and High Lawn, Broad Oak Park, Worsley, near Manchester.

1873. Cheesman, William Talbot, Hartlepool Rope Works, Hartlepool.

1881. Chilcott, William Winsland, The Terrace, H.M. Dockyard, Sheerness.

1895. Chittenden, Edmund Barrow, West Malling, Kent.

1880. Churchward, George Dundas, Locomotive Superintendent, Imperial Chinese Railways, care of H.B.M.'s Consulate, Tientsin, North China: (or care of A. W. Churchward, London Chatham and Dover Railway, Queenborough Pier, Queenborough.)

1894. Churchward, George Jackson, Great Western Railway Carriage Works, Swindon.

1896. Claremont, Ernest Alexander, Messrs. F. H. Royce and Co., Cooke Street, Hulme, Manchester. [*Switch, Manchester.* 772.]

1891. Clark, Augustus, Bowman's Heirs, Pernambuco, Brazil.

1871. Clark, Christopher Fisher, Mining Engineer, Garswood Coal and Iron Co., Park Lane Collieries, Wigan; and Cranbury Lodge, Park Lane, Wigan. [*Park Lane, Wigan.*]

1878. Clark, Daniel Kinnear, 8 Buckingham Street, Adelphi, London, W.C.

1867. Clark, George, Southwick Engine Works, near Sunderland.

1896. Clark, George, Jun., Southwick Engine Works, near Sunderland.

1889. Clark, Thomas Alexander, Superintendent of Workshops, George Heriot's Hospital School, Edinburgh.

1896. Clark, Thomas Forster, Locomotive Superintendent, Metropolitan Railway, Neasden, London, N.W.

1894. Clarkson, Charles, Portland Harbour Torpedo Works, Weymouth.

1891. Clarkson, Thomas, Grove Villa, Carshalton Grove, Sutton, Surrey.

1892. Clay, Charles Butler, National Telephone Co., St. Andrew's House, Holborn Circus, London, E.C.

1882. Clayton, William Wikeley, Messrs. Hudswell Clarke and Co., Railway Foundry, Jack Lane, Leeds. [*Loco, Leeds.* 504.]

1890. Cleathero, Edward Thomas, Messrs. Cleathero and Nichols, Phœnix Works, Boleyn Road, Kingsland, London, N.; and 16 Tollington Place, London, N.

1890. Cleaver, Arthur, Engineer, Nottingham Laundry Co., Sherwood, near Nottingham; and Hornby House, Sherwood, near Nottingham.

1890. Cleland, William, Sheffield Testing Works, Blonk Street, Sheffield.

1871. Cleminson, James, Dashwood House, 9 New Broad Street, London, E.C. [*Cleminson, London.*]

1873. Clench, Frederick, Lincoln Works, Chesterfield.

1885. Clifton, George Bellamy, Great Western Railway Electric Light Works, 150 Westbourne Terrace, Paddington, London, W.

1885. Close, John, Jun., York Engineering Works, Leeman Road, York.

1885. Clutterbuck, Herbert, Engineers' Department, London County Council, Spring Gardens, London, S.W.

1881. Cochrane, Brodie, Greencroft Park, Lanchester, Durham.

1858. Cochrane, Charles, Woodside Iron Works, near Dudley; and Green Royde, Pedmore, near Stourbridge.

1887. Cochrane, George, Resident Engineer, London Hydraulic Power Works, 46 Holland Street, Blackfriars Road, London, S.E.

1885. Cochrane, John, Grahamston Foundry and Engine Works, Barrhead, near Glasgow. [*Cochrane, Barrhead.*]

1869. Cochrane, Joseph Bramah, Woodside Iron Works, near Dudley.

1868. Cochrane, William, Mining Engineer, Elswick Colliery, Elswick, Newcastle-on-Tyne; and Oakfield House, Gosforth, Newcastle-on-Tyne.

1864. Coddington, Sir William, Bart., M.P., Ordnance Cotton Mill, Blackburn; and Wycollar, Blackburn.

1889. Coey, Robert, Locomotive Engineer, Great Southern and Western Railway, Inchicore Works, near Dublin.

1889. Colam, William Newby, 57 Henderson Row, Edinburgh. [*Colam, Cable, Edinburgh.*]

1892. Cole, Henry Aylwin Bevan, 79½ Gracechurch Street, London, E.C. [*Carbuncle, London.*]

1878. Coles, Henry James, Sumner Street, Southwark, London, S.E.

1884. Coltman, John Charles, Messrs. Huram Coltman and Son, Engineering Works, Meadow Lane, Loughborough.

1878. Colyer, Frederick, 18 Great George Street, Westminster, S.W.

1888. Combe, Abram, Messrs. Combe Barbour and Combe, Falls Foundry, Belfast.

1889. Common, John Freeland Fergus, 4 Bute Crescent, Cardiff.

1881. Compton-Bracebridge, John Edward, Messrs. Easton Anderson and Goolden, 3 Whitehall Place, London, S.W.

1896. Conaty, George, Engineer, Birmingham and Midland Tramways, Birmingham.

1888. Constantine, Ezekiel Grayson, 32 Victoria Street, Manchester. [*Constant, Manchester.*]

1886. Conyers, Sidney Ward, Railway Construction Branch, Public Works Department, Sydney, New South Wales.

1874. Conyers, William, Albury, New South Wales.

1896. Cook, Charles, Messrs. Barry, Henry and Co., 64 Mark Lane, London, E.C.

1888. Cook, John Joseph, Messrs. Robinson Cooks and Co., Atlas Foundry, St. Helen's, Lancashire.

1892. Cooke, Rupert Thomas, 31 Granville Street, Ashton-under-Lyne.

1877. Cooper, Arthur, North Eastern Steel Co., Royal Exchange, Middlesbrough.

1883. Cooper, Charles Friend, Messrs. Paterson and Cooper, 68 Victoria Street, Westminster, S.W. [*Patella, London.* 1140.]

1877. Cooper, George, Pencliffe, Alleyne Road, West Dulwich, London, S.E.

1891. Cooper, Myles, 36 Victoria Street, Manchester.

1874. Cooper, William, Neptune Engine Works, Hull. [*Neptune, Hull.*]

1881. Coote, Arthur, Messrs. R. and W. Hawthorn Leslie and Co., Hebburn, Newcastle-on-Tyne.

1885. Coppée, Evence, 223 Avenue Louise, Bruxelles, Belgium.

1892. Corin, Philip Burne, Messrs. J. M. B. Corin and Son, Anchor Foundry, Penzance.

1895. Corner, John Frederick, Boiler Insurance and Steam Power Co., 67 King Street, Manchester.

1895. Cornish, Edwin, Staff Engineer, R.N., H.M.S. "Hawke," Mediterranean Station.

1848. Corry, Edward (*Life Member*), 9 New Broad Street, London, E.C.

1881. Cosser, Thomas, McLeod Road Iron Works, Kurrachee, India: (or care of Messrs. Ironside Gyles and Co., 1 Gresham Buildings, Guildhall, London, E.C.)

1883. Cotton, Henry Streatfeild, London Hydraulic Power Co., Palace Chambers, Bridge Street, Westminster, S.W.

1896. Cottrell, Stephen Butler, Pacific Buildings, 31 James Street, Liverpool. [*Motor, Liverpool.* 5460.]

1894. Cottrill, John Ormerod, Bee Hive Works, Bolton.

1887. Coulman, John, Hull and Barnsley Railway, Spring Head Works, Hull.

1895. Couper, Sinclair, Messrs. Lindsay Burnet and Co., Moore Park Boiler Works, Govan, Glasgow. [*Burnet, Glasgow.* 1513.]

1878. Courtney, Frank Stuart, Messrs. Easton Anderson and Goolden, 3 Whitehall Place, London, S.W.; and 39 Alleyn Park, Dulwich, London, S.E.

1875. Coward, Edward, Messrs. Melland and Coward, Cotton Mills and Bleach Works, Heaton Mersey, near Manchester.

1896. Cowdell, Henry Charles, Cradley Boiler Works, Cradley Heath, S.O., Staffordshire. [*Boiler, Cradley Heath.*]

1875. Cowen, Edward Samuel, Messrs. G. R. Cowen and Co., Beck Works, Brook Street, Nottingham; and 9 The Ropewalk, Nottingham. [*Cowen, Nottingham.* 87.]

1880. Cowper, Charles Edward, 144 Addison Gardens, London, W.

1892. Cowper-Coles, Sherard Osborn, 39 Victoria Street, Westminster, S.W.; and 16 Adam Street, Manchester Square, London, W.

1888. Cox, Herbert Henry, 17 Wodehouse Terrace, Falmouth.

1896. Craig, Alexander, Messrs. A. and G. Craig, Queen's Quay and Boating Club Road, Londonderry.

1866. Craven, William, Messrs. Craven Brothers, Vauxhall Iron Works, Osborne Street, Manchester. [*Vauxhall, Manchester.* 659.]

1894. Craven, William H. S., Messrs. Craven Brothers, Vauxhall Iron Works, Osborne Street, Manchester. [*Vauxhall, Manchester.* 659.]

1889. Cribb, Frederick James, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough.

1884. Crighton, John, Messrs. Crighton and Co., 20 Exchange Buildings, St. Mary's Gate, Manchester.

1893. Crippin, Thomas Henry, Bolton Engineering Co., Turton Street, Bolton; and 89 Bury New Road, Bolton.

1883. Croft, Henry, M.P., Chemanns, Vancouver Island.

1878. Crohn, Frederick William, 14 Burney Street, Greenwich, London, S.E.

1877. Crompton, Rookes Evelyn Bell, Arc Works, Chelmsford; and Mansion House Buildings, Queen Victoria Street, London, E.C. [*Crompton, Chelmsford.*]

1884. Crook, Charles Alexander, Telegraph Construction and Maintenance Works, Enderby's Wharf, East Greenwich, London, S.E.

1881. Crosland, James Foyell Lovelock, Chief Engineer, Boiler Insurance and Steam Power Co., 67 King Street, Manchester.

1891. Crosland, Joseph, Messrs. Seebohm and Dieckstahl, Dannemora Steel Works, Sheffield; and Stanley Avenue, Birkdale, Southport.

1875. Crossley, William John, Messrs. Crossley Brothers, Great Marlborough Street, Manchester. [*Crossleys, Openshaw.*]

1882. Cruickshank, William Douglass, Chief Government Engineer Surveyor, Marine Board, Sydney, New South Wales.

1889. Cullen, William Hart, Resident Engineer, The Aluminium Co., Oldbury, near Birmingham.

1887. Cutler, George Benjamin, Messrs. Samuel Cutler and Sons, Providence Iron Works, Millwall, London, E.; and 4 Westcombe Park, Blackheath, London, S.E.

1876. Cutler, Samuel, Messrs. Samuel Cutler and Sons, Providence Iron Works, Millwall, London, E. [*Cutler, Millwall.* 5059.]

1888. Dadabhoy, Cursetjee, Messrs. Shapurji Sorabji and Co., Bombay Foundry and Engine Works, Khetwady, Bombay, India; and Cumbala Hill, Bombay, India.

1864. Daglish, George Heaton, Rock Mount, St. Anne's Road, Aigburth, near Liverpool. [*Daglish, Aigburth.* 2717.]

1891. Daglish, Harry Bolton, Messrs. Robert Daglish and Co., St. Helen's Engine and Boiler Works, St. Helen's, Lancashire.

1895. Daintree, Thomas Ekins, Messrs. Tangyes, P.O. Box 818, Johannesburg, Transvaal, South Africa.

1883. D'Albert, Charles, Société des Anciens Établissements Hotchkiss et Cie., 6 Route de Gonesse, St. Denis, Seine, France.

1890. Dalby, William Ernest, Finsbury Technical College, Leonard Street, City Road, London, E.C.

1889. Dalgarno, James Robert, Danesford, Countess Wells Road, Mannofield, Aberdeen.

1893. Dall, John, Messrs. Harland and Wolff, Belfast.

1893. Dalrymple, Alexander, Superintendent Engineer, Hall Line of Steamers, 19 Tower Buildings N., Water Street, Liverpool.

1881. D'Alton, Patrick Walter, London Electric Supply Corporation, Stowage Wharf, Deptford, London, S.E.

1866. Daniel, Edward Freer, Messrs. Worthington and Co., The Brewery, Burton-on-Trent; and 89 Derby Street, Burton-on-Trent.

1866. Daniel, William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds; and Fern Bank, Horsforth, Leeds.

1891. Daniels, Thomas, Messrs. Nasmyth Wilson and Co., Patricroft, Manchester.

1888. Darbishire, James Edward, 110 Cannon Street, London, E.C. [*Ezra, London.* 11306.]

1878. Darwin, Horace (*Life Member*), The Orchard, Huntingdon Road, Cambridge.

1873. Davey, Henry, Messrs. Hathorn Davey and Co., Sun Foundry, Dewsbury Road, Leeds [*Sun Foundry, Leeds*]; and 3 Prince's Street, Westminster, S.W. [*Subterranean, London.*]

1890. Davidson, Albert, 139 Norfolk Street, Sheffield.

1888. Davidson, Samuel Cleland, Sirocco Works, Bridge End, Belfast.

1880. Davies, Charles Merson, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow; and Leslie House, Pollokshields, Glasgow.

1885. Davies, Edward John Mines, 24 Harrington Square, London, N.W.

1891. Davies, John Hubert, P.O. Box 455, Johannesburg, Transvaal, South Africa.

1894. Davis, George, Engineer's Office, Lancashire and Yorkshire Railway, Hunt's Bank, Manchester.

1868. Davis, Henry Wheeler, 5 Highbury Grove, Highbury, London, N.

1877. Davison, John Walter, Bombay Baroda and Central India Railway, Ahmedabad, India: (or care of Mrs. Channon, 97 Shirland Road, Maida Vale, London, W.)

1884. Davison, Robert, Locomotive Department, Caledonian Railway, St. Rollox, Glasgow.

1873. Davy, David, Broom Croft, Parkhead, Sheffield.

1892. Davy, William James, 15 Victoria Street, Westminster, S.W.

1874. Daw, Samuel, 50 Chelsea Road, Southsea, Portsmouth.

1879. Dawson, Bernard, 110 Cannon Street, London, E.C. [*Crocus, London*]; and The Laurels, Malvern Link, Malvern. [*Heather, Malvern Link.*]

1875. Dawson, Edward, 2 Windsor Place, Cardiff. [*Mechanical, Cardiff.*]

1896. Day, Charles, Messrs. Cole, Marchent and Morley, Prospect Foundry, Bradford.

1890. Day, George Cameron, Messrs. Day Summers and Co., Northam Iron Works, Southampton.

1886. Dayson, William Ogden, Blaenavon Works, Blaenavon, R.S.O., Monmouthshire.

1874. Deacon, George Frederick, 32 Victoria Street, Westminster, S.W.

1880. Deacon, Richard William, Boeboetan, Battenhall Road, Worcester.

1894. Deakin, Benjamin Walter, Resident Engineer, City of London Electric Lighting Station, 64 Bankside, Southwark, London, S.E.; and Belmont, St. Ann's Hill, Wandsworth, London, S.W.

1868. Dean, William, Locomotive Superintendent, Great Western Railway, Swindon.

1887. Deas, James, Clyde Navigation, Glasgow.

1866. Death, Ephraim, Messrs. Death and Ellwood, Albert Works, Leicester.

1884. Decauville, Paul, Portable Railway Works, Petit Bourg, Seine-et-Oise, France. [*Decauville, Corbeil.*]

1890. Deeley, Richard Mountford, Locomotive Department, Midland Railway, Derby; and 10 Charnwood Street, Derby.

1877. Dees, James Gibson, 36 King Street, Whitehaven.

1889. Defries, Wolf, Messrs. Defries and Sons, 147 Houndsditch, London, E. [*Defries, London.*]

1882. Denison, Samuel, Messrs. Samuel Denison and Son, Old Grammar School Foundry, North Street, Leeds. [*Weigh, Leeds.* 221.]

1892. Dennis, George D., 26 Newton Road, Bayswater, London, W.

1888. Dent, Charles Hastings, London and North Western Railway, Lime Street Station, Liverpool.

1895. Dewhurst, John Henry, Messrs. John Dewhurst and Son, Attercliffe Road, Sheffield. [1614.]

1883. Dick, Frank Wesley, Palmers Shipbuilding and Iron Works, Jarrow.

1891. Dick, John Norman, Government Marine Surveyor, Penang, Straits Settlements.

1890. Dickinson, Alfred, 120 Colmore Row, Birmingham. [*Traction, Birmingham.*]

1891. Dickinson, James Clark, Palmer's Hill Engine Works, Sunderland.

1880. Dickinson, John, Palmer's Hill Engine Works, Sunderland. [*Bede, Sunderland.*]

1892. Dickinson, Richard Henry, Locomotive Superintendent, Birmingham Central Tramways, Kyotts Lake Depôt, Birmingham.

1875. Dickinson, William, Warham Road, Croydon.

1886. Dixon, Robert, 4 Tyne Vale Terrace, Gateshead.

1883. Dixon, Samuel, Messrs. Kendall and Gent, Victoria Works, Springfield, Salford, Manchester. [*Tools, Manchester.* Nat. 330; Mutual 1330.]

1887. Dixon, William Basil, 18 Westcott Street, Hull.

1896. Dobson, Adam, 7 Marsh's Buildings, Donegall Street, Belfast. [966.]

1872. Dobson, Benjamin Alfred, Messrs. Dobson and Barlow, Kay Street Machine Works, Bolton. [*Dobsons, Bolton.*]

1873. Dobson, Richard Joseph Caistor, De Volharding, Soerabaya, Java: (or care of Miss Dobson, 4 Chesterfield Buildings, Victoria Park, Clifton, Bristol.)

1880. Dodd, John, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1868. Dodman, Alfred, Highgate Foundry, Lynn. [*Dodman, Lynn.*]

1889. Dolby, Ernest Richard, 8 Prince's Street, Westminster, S.W.

1880. Donald, James, 43 East Mount, Barrow-in-Furness.

1876. Donaldson, John, Messrs. John I. Thornycroft and Co., Steam Yacht and Launch Builders, Church Wharf, Chiswick, London, W.; and Tower House, Turnham Green.

1873. Donkin, Bryan (*Life Member*), Messrs. Bryan Donkin and Co., 55 Southwark Park Road, Bermondsey, London, S.E. [*Donkin Company, London.* 4662.]; and The Mount, Wray Park, Reigate.

1895. Donkin, Harry Julyan, Works Manager, Messrs. Bryan Donkin and Co., 55 Southwark Park Road, Bermondsey, London, S.E.

1891. Donovan, Edward Wynne, Messrs. J. S. Leach and Co., Broughton Bridge Iron Works, Salford, Manchester. [*Dazzle, Manchester.*]

1896. Dorman, William Sansom, Works Manager, Gloucester Wagon Works, Gloucester.

1865. Douglas, Charles Prattman (*Life Member*), Thornbeck Hill, Carmel Road, Darlington.

1879. Douglass, Sir James Nicholas, F.R.S., Stella House, Bonchurch, Ventnor.

1879. Douglass, William, Chief Engineer to the Commissioners of Irish Lights, Westmoreland Street, Dublin.

1891. Douglass, William James, Messrs. Douglass Brothers, Globe Iron Works, Blaydon-on-Tyne, R.S.O., County Durham.

1887. Douglass, William Tregarthen, 15 Victoria Street, Westminster, S.W.

1857. Dove, George, Messrs. Cowans Sheldon and Co., St. Nicholas Engine and Iron Works, Carlisle; and Viewfield, Stanwix, near Carlisle.

1873. Dove, George, Redbourn Hill Iron and Coal Co., Frodingham, near Doncaster [*Redbourn, Frodingham.*]; and Hodroyd Hall, near Barnsley.

1866. Downey, Alfred C., Messrs. Downey and Co., Coatham Iron Works, Middlesbrough; and Belle Vue, Marton Road, Middlesbrough.

1881. Dowson, Joseph Emerson, 39 Old Queen Street, Westminster, S.W. [*Gaseous, London.*]

1880. Doxford, Robert Pile, Messrs. William Doxford and Sons, Pallion Shipbuilding and Engine Works, Sunderland.

1874. Dredge, James, 35 Bedford Street, Strand, London, W.C. [3663.]

1890. Drewet, Tom, Government Senior Inspector of Steam Boilers, Town Custom House, Bombay, India.

1896. Dronsfield, William, Messrs. Dronsfield Brothers, Atlas Works, Oldham.

1886. Drummond, Dugald, Locomotive Engineer, London and South Western Railway, Nine Elms, London, S.W.

1889. Drummond, Richard Oliver Gardner, P. O. Box 92, Johannesburg, Transvaal, South Africa.

1896. Dryden, Thomas, Grimshaw Street Foundry, Preston. [36.]

1877. Dübs, Charles Ralph, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow.

1885. Duckering, Charles, Water Side Works, Rosemary Lane, Lincoln.

1880. Duckham, Frederic Eliot, Engineer, Millwall Docks, London, E.

1868. Dugard, William Henry, Messrs. Dugard Brothers, Vulcan Rolling Mills, Bridge Street West, Summer Lane, Birmingham. [*Vulcan, Birmingham.*]

1879. Duncan, David John Russell, 28 Victoria Street, Westminster, S.W.

1886. Duncan, Norman, Mechanical Engineer to the Municipality, Rangoon, British Burmah, India.

1894. Dunell, George Robert, 36 Bedford Street, Strand, London, W.C.; and 9 Grove Park Terrace, Chiswick, London, W.

1892. Dunlop, James, Victoria Jubilee Technical Institute, Byculla, Bombay, India.

1870. Dunlop, James Wilkie, 39 Delancey Street, Regent's Park, London, N.W.

1890. Dunn, Hugh Shaw, Engineer, Caprington Collieries, Kilmarnock.

1886. Duvall, Charles Anthony, Messrs. Easton, Anderson and Goolden, Erith Iron Works, Erith, S.O., Kent.

1887. Dymond, George Cecil, Messrs. W. P. Thompson and Co., 6 Lord Street, Liverpool.

1865. Dyson, Robert, Messrs. Owen and Dyson, Rother Iron Works, Rotherham.

1880. Eager, John Edward, Messrs. William Crichton and Co., Engineering and Shipbuilding Works, Abo, Finland.

1869. Earnshaw, William Lawrence, Superintending Marine Engineer, South Eastern Railway, Folkestone.

1858. Easton, Edward, 11 Delahay Street, Westminster, S.W.

1884. Eastwood, Charles, Manager, Linacre Gas Works, Liverpool.

1892. Eastwood, Thomas Carline, Messrs. Eastwood Swingler and Co., Victoria and Railway Iron Works, Derby. [*Swingler, Derby.*]

1888. Eaton-Shore, George, Borough Engineer, Temple Chambers, Crewe.

1875. Eaves, William, Engineer, Messrs. John Brown and Co., Atlas Steel and Iron Works, Sheffield.

1896. Eborall, Cornelius Willes, District Locomotive Superintendent, East Indian Railway, Jamalpur, India: (or care of Messrs. William Watson and Co., 7 Waterloo Place, Pall Mall, London, S.W.)

1878. Eckart, William Roberts, Messrs. Salkeld and Eckart, 632 Market Street, P. O. Box 1844, San Francisco, California, United States.

1868. Eddison, Robert William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1886. Ede, Francis Joseph, Messrs. Ede Brothers, Silchar, Cachar, India.

1893. Eden, The Hon. Francis Fleetwood, Los Talleres de Sola, Ferro Carril del Sud, Buenos Aires, Argentine Republic.

1887. Edlin, Herbert William, P.O. Box 674, Johannesburg, Transvaal, South Africa. [*Motor, Johannesburg.*]

1883. Edmiston, James Brown, Marine Superintending Engineer, Messrs. Hamilton Fraser and Co., K Exchange Buildings, Liverpool; and Ivy Cottage, Highfield Road, Walton, Liverpool.

1877. Edwards, Frederick, 62 Bishopsgate Street Within, London, E.C.

1885. Edwards, Walter Cleeve, Public Works Department, Vryburg, British Bechuanaland, South Africa.

1896. Ekin, Tom Charles, 21 Old Queen Street, Westminster, S.W.

1888. Ellery, Henry George, 7 Fernbank Road, Redland, Bristol.

1875. Ellington, Edward Bayzand, Hydraulic Engineering Works, Chester; and Hydraulic Engineering Co., Palace Chambers, 9 Bridge Street, Westminster, S.W.

1892. Elliott, Archibald Campbell, D.Sc., Professor of Engineering, University College of South Wales and Monmouthshire, Cardiff.

1895. Elliott, George, 10 Oceanic Avenue, Belfast.

1883. Elliott, Henry John, Assistant Manager, Elliott's Metal Works, Selly Oak, near Birmingham. [*Elmeco, Birmingham.*]

1882. Elliott, Thomas Graham, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds.

1895. Ellis, Arthur Devonshire, Managing Director, Messrs. Thwaites Brothers, Vulcan Iron Works, Bradford.

1892. Ellis, Joseph S., Central Engineering Works, Chepstow [*Engineer, Chepstow.*]; and Myrtle Cottage, Chepstow.

1880. Ellis, Oswald William, 6 Grosvenor Place, Jesmond, Newcastle-on-Tyne. [*Robey, Newcastle-on-Tyne.*]

1896. Ellis, William Frederick Wood, 2 Dulal Street, Fort, Bombay, India.

1885. Elsworthy, Edward Houtson, Messrs. Richardson and Cruddas, Byculla Iron Works, Bombay, India; and Altamont Road, Cumbala Hill, Bombay, India.

1878. Elwin, Charles, London County Council, Spring Gardens, London, S.W.

1890. English, Lt.-Colonel Thomas, Hawley, near Dartford.

1894. English, Thomas Matthew, Superintendent, Die and Coining Department, H. M. Mint, Bombay, India.

1894. Ennor, Charles John, 55 Rua da Reboleira, Oporto, Portugal.

1890. Esson, John, Chatteris Engineering Works, Chatteris, S.O., Cambridgeshire.

1889. Etches, Harry, 17 Napoleon Street, Brantford, Ontario, Canada.

1884. Etherington, John, 39A King William Street, London Bridge, London, E.C.

1887. Evans, Arthur George, Palace Chambers, 9 Bridge Street, Westminster, S.W.

1884. Evans, David, Messrs. Bolckow Vaughan and Co., Cleveland Iron and Steel Works, South Bank, R.S.O., Yorkshire.

1892. Evanson, Frederic Macdonnell, Hazelhurst, Urmston, near Manchester.

1887. Everard, John Breedon, 6 Millstone Lane, Leicester.

1887. Everitt, Nevill Henry, Messrs. Thomas Piggott and Co., Atlas Works, Birmingham; and Hillside, Knowle, Warwickshire.

1894. Ewen, John Taylor, 4 Ann Street, Hillhead, Glasgow.

1881. Ewen, Thomas Buttwell, Messrs. Ewen and Mitton, Smithfield Works, Sherlock Street, Birmingham.

1891. Ewing, James Alfred, F.R.S., Professor of Mechanism and Applied Mechanics, Engineering Department, The University, Cambridge; and Langdale Lodge, Cambridge.

1890. Exton, George Gaskell, Messrs. Chubb and Son, 128 Queen Victoria Street, London, E.C.

1868. Fairbairn, Sir Andrew, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds; and Askham Richard, York.

1875. Farcot, Jean Joseph Léon, Messrs. Farcot and Sons, Engine Works, 13 Avenue de la Gare, St. Ouen, France.

1880. Farcot, Paul, Messrs. Farcot and Sons, Engine Works, 13 Avenue de la Gare, St. Ouen, France.

1881. Farrar, Sidney Howard, Messrs. Howard Farrar and Co., Port Elizabeth, South Africa; and care of Messrs. F. A. Robinson and Co., 54 Old Broad Street, London, E.C.

1882. Fawcett, Thomas Constantine, White House Engineering Works, Leeds. [*Fawcett, Leeds.*]

1882. Feeny, Victor Isidore, 60 Queen Victoria Street, London, E.C. [*Victor Feeny, London.*]

1876. Fell, John Corry, 1 Queen Victoria Street, London, E.C.; and Excelsior Works, Old Street, London, E.C.

1869. Fenwick, Clennell, 57 Gracechurch Street, London, E.C.

1892. Fenwick, James, 19 Bridge Street, Sydney, New South Wales. [1038.]

1870. Ferguson, Henry Tanner, Wolleigh, Bovey Tracey, near Newton Abbot.

1881. Ferguson, William, Harbour Board, Wellington, New Zealand: (or care of Montgomery Ferguson, 81 James Street, Dublin.)

1896. Ferguson, William Deeble, General Manager, Messrs. Victor Coates and Co., Lagan Engine Works, Belfast; and Albert Villa, Ravenhill Road, Belfast.

1866. Fiddes, Walter, Clapton Villa, Belgrave Road, Tyndall's Park, Bristol.

1867. Field, Edward, 4 Trafalgar Square, London, W.C.

1888. Field, Howard, 12 London Street, Fenchurch Street, London, E.C.

1884. Fielden, Joseph Petrie, Messrs. Thomas Robinson and Son, Railway Works, Rochdale; and Park Terrace, Rochdale.

1874. Fielding, John, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester. [*Atlas, Gloucester.*]

1891. Finlayson, Finlay, East End Villa, Lugar Street, Coatbridge.

1891. Firth, George Henry, Field Head, Bolton, Bradford.

1888. Fischer, Gustave Joseph, Railway Construction Branch, Public Works Department, Sydney, New South Wales; and Oakhurst, West Street, North Sydney, New South Wales.

1889. Fisher, Henry Bedwell, Marine Shops, London Brighton and South Coast Railway, Newhaven, Sussex.

1884. Fisher, Henry Oakden, Ty Mynydd, Radyr, near Cardiff.

1888. FitzGerald, Maurice Frederick, Professor of Engineering, Queen's College, Belfast.

1877. Flannery, James Fortescue, M.P., 9 Fenchurch Street, London, E.C. [2283.]

1883. Fletcher, George, Masson and Atlas Works, Litchurch, Derby.

1867. Fletcher, Lavington Evans, Chief Engineer, Manchester Steam Users' Association, 9 Mount Street, Albert Square, Manchester. [*Steam Users', Manchester.*]

1892. Focken, Charles Frederick, care of Institute of Engineers and Shipbuilders, Hong Kong, China.

1859. Fogg, Robert, 159 Knight's Hill, West Norwood, London, S.E.

1887. Foley, Nelson, Engineering Manager, Società Industriale Napoletana Hawthorn-Guppy, Naples, Italy.

1882. Forbes, David Moncur, Engineer, H. M. Mint, Bombay.

1892. Forbes, Percy Alexander, Messrs. Lambert Brothers, Tube Mills, Iron and Brass Works, Walsall.

1882. Forbes, William George Loudon Stuart, Mechanical Superintendent, H. M. Mint, Calcutta.

1892. Forrest, Hilary Sheldon, General Manager, Messrs. Dobson and Barlow, Kay Street Machine Works, Bolton.

1888. Forster, Alfred Llewellyn, Assistant Engineer, Newcastle and Gateshead Water Works, Newcastle-on-Tyne.

1882. Forsyth, Robert Alexander, Courtway, Gold Tops, Newport, Monmouthshire.

1889. Foster, Ernest Howard, Messrs. Henry R. Worthington, 86 Liberty Street, New York, United States.

1889. Foster, Herbert Anderton (*Life Member*), Messrs. John Foster and Son, Black Dike Spinning Mills, Queensbury, near Bradford.

1888. Foster, James, Lily Bank, St. Andrew's Drive, Pollokshields, Glasgow.

1884. Foster, John Slater, Messrs. Jones and Foster, 39 Bloomsbury Street, Birmingham.

1882. Fothergill, John Reed, Consulting Engineer, Dock Office, West Hartlepool; and 1 Bathgate Terrace, West Hartlepool.

1877. Foulis, William, Manager, Glasgow Corporation Gas Department, City Chambers, 45 John Street, Glasgow.

1885. Fourny, Hector Foster, French Chambers, Queen's Dock-Side, Hull. [*Veritas, Hull.*]

1866. Fowler, George, Basford Hall, near Nottingham.

1847. Fowler, Sir John, Bart., K.C.M.G., 2 Queen Square Place, Westminster, S.W.

1894. Fowler, Robert Henry, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds. [*Fowler, Leeds.*]

1885. Fowler, William Henry, 31 Whitworth Street, Manchester; and Brook House, Flixton, near Manchester.

1866. Fox, Sir Douglas, 28 Victoria Street, Westminster, S.W.

1875. Fox, Samson, Leeds Forge, Leeds.

1884. Frampton, Edwin, General Engine and Boiler Co., Hatcham Iron Works, Pomeroy Street, New Cross Road, London, S.E. [*Oxygen, London.* 8007.]

1885. Franki, James Peter, Morts Dock and Engineering Co., Morts Bay, Sydney, New South Wales: (or care of Messrs. Goldsbrough Mort and Co., 149 Leadenhall Street, London, E.C.)

1877. Fraser, John Hazell, Messrs. John Fraser and Son, Millwall Boiler Works, London, E.; and 110 Cannon Street, London, E.C.

1888. Frenzel, Arthur Benjamin, 314 W. 133rd Street, New York, United States.

1891. Frier, John Drummond, 186 Plumstead Common Road, Plumstead.
1866. Fry, Albert, Bristol Wagon Works, Lawrence Hill, Bristol.
1891. Fuller, Charles Frederick, 171 Queen Victoria Street, London, E.C.
1884. Furness, Edward, Knollcroft, Knoll Road, Bexley, S.O., Kent.

1890. Gadd, William, Assistant Locomotive Engineer, Waterford and Limerick Railway, Limerick.
1866. Galloway, Charles John, Managing Director, Messrs. Galloways, Knott Mill Iron Works, Manchester. [*Galloway, Manchester.*]
1862. Galton, Sir Douglas, K.C.B., D.C.L., LL.D., F.R.S., 12 Chester Street, Grosvenor Place, London, S.W.
1884. Ganga Ram, Rai Bahadur, Executive Engineer, Public Works Department, Amritsar, Punjaub, India: (or care of Messrs. Thomas Wilson and Co., 24 Rood Lane, London, E.C.)
1891. Garrard, Charles Riley, Garrard Manufacturing Co., Magneto Works, Ryland Street, Birmingham. [*Gearing, Birmingham.* 904.]
1882. Garrett, Frank, Messrs. Richard Garrett and Sons, Leiston Works, Leiston, R.S.O., Suffolk. [*Garrett, Leiston.*]
1894. Gatehouse, Tom Ernest, 22 Paternoster Row, London, E.C. [*Ageekay, London.*]
1867. Gauntlett, William Henry, 33 Albert Terrace, Middlesbrough. [*Pyrometer, Middlesbrough.*]
1895. Gaynor, Captain Henry Francis, R.E., School of Military Engineering, Chatham.
1888. Gaze, Edward Henry James, 4 Victoria Drive, Mount Florida, Glasgow.
1895. Geach, Frederick Samuel, Messrs. John Vipond and Co., Varteg Hill Colliery, near Pontypool.
1888. Geddes, Christopher, 2A Drury Buildings, Water Street, Liverpool. [*Graccius, Liverpool.*]
1880. Geoghegan, Samuel, Messrs. A. Guinness Son and Co., St. James' Gate Brewery, Dublin. [*Guinness, Dublin.*]
1896. German, Walter Hussey, Colonial Sugar Refining Co., Sydney, New South Wales.
1887. Gibb, Andrew, Managing Engineer, Messrs. Rait and Gardiner, Millwall Docks, London, E.; and 30 South Street, Greenwich, London, S.E.
1871. Gibbins, Richard Cadbury, Berkley Street, Birmingham. [*Gibbins, Birmingham.*]
1883. Gilchrist, Percy Carlyle, F.R.S. (*Life Member*), Palace Chambers, 9 Bridge Street, Westminster, S.W. [*Gilchrist, London*]; and Frognal Bank, Finchley New Road, Hampstead, London, N.W.

1880. Gill, Charles, Messrs. Young and Gill, Engineering Works, Java; and Java Lodge, Beckenham.

1889. Gill, Frederick Henry, Messrs. Alexander Penney and Co., 107 Fenchurch Street, London, E.C.

1884. Gimson, Arthur James, Messrs. Gimson and Co., Engine Works, Vulcan Street, Leicester. [*Gimson, Leicester.* 6.]

1881. Girdwood, William Wallace, 24 Plashet Road, Upton Manor, London, E.

1874. Gjers, John, Messrs. Gjers Mills and Co., Ayresome Iron Works, Middlesbrough.

1896. Glasgow, Arthur Graham, Messrs. Humphreys and Glasgow, 9 Victoria Street, Westminster, S.W.

1887. Gledhill, Manassah, Sir Joseph Whitworth and Co., Openshaw, Manchester.

1880. Godfrey, William Bernard, 23 St. Swithin's Lane, London, E.C.

1888. Goff, John, Messrs. Salt and Co., The Brewery, Burton-on-Trent.

1882. Goldsmith, Alfred Joseph, Lillington, Moray Street, New Farm, Brisbane, Queensland.

1877. Goodbody, Robert, Messrs. Goodbody, Clashawaun Jute Factory, Clara, near Moate, Ireland.

1875. Goodfellow, George Ben, Messrs. Goodfellow and Matthews, Hyde Iron Works, Hyde, near Manchester. [*Goodfellow, Hyde.*]

1890. Goodman, John, Professor of Engineering, Yorkshire College, Leeds.

1889. Goold, William Tom, Shillingford Works, Wallingford.

1865. Göransson, Göran Fredrick, Sandvik Iron Works, near Gefle, Sweden: (or care of James Bird, 143 Cannon Street, London, E.C.)

1887. Gordon, Alexander, Niles Tool Works, and Messrs. Gordon and Maxwell, Hamilton, Ohio, United States.

1879. Gorman, William Augustus, Messrs. Siebe and Gorman, 187 Westminster Bridge Road, London, S.E. [*Siebe, London.*]

1880. Gottschalk, Alexandre, 13 Rue Auber, Paris.

1877. Goulty, Wallis Rivers, Messrs. Wheatley Kirk, Price, and Goulty, Albert Chambers, Albert Square, Manchester. [*Indicator, Manchester.*]

1878. Grafton, Alexander, Vulcan Works, Bedford. [*Grafton, Bedford.*]

1894. Graham, Maurice, Transport Appliance Works, Brook Street, Smethwick, Birmingham.

1896. Graham, Robert, Ponce, Porto Rico.

1886. Grant, Percy, Assistant Locomotive, Carriage, and Wagon Superintendent, Sola Works, Ferro Carril del Sud, Buenos Aires, Argentine Republic: (or care of John M. Grant, 136 Sutherland Avenue, Maida Vale, London, W.)

1895. Grant, Thomas Maxwell, Managing Director, Messrs. Napier Brothers, 100 Hyde Park Street, Glasgow. [*Windlass, Glasgow.* 714.]

1891. Gray, George Macfarlane (*Life Member*), Board of Trade Surveyors' Office, Custom House Arcade, Liverpool.

1865. Gray, John Macfarlane, Chief Examiner of Engineers, Marine Department, Board of Trade, 79 Mark Lane, London, E.C.; and 4 Ladbroke Crescent, Notting Hill, London, W. [*Yarg, London.*]

1876. Gray, John William, Engineer, Corporation Water Works, Broad Street, Birmingham.

1879. Gray, Thomas Lowe, Lloyd's Register, 2 White Lion Court, Cornhill, London, E.C.; and 24 St. Michael's Road, Stockwell, London, S.W.

1879. Greathead, James Henry, 15 Victoria Street, Westminster, S.W.

1861. Green, Sir Edward, Bart., Messrs. E. Green and Son, Phœnix Works, Wakefield.

1888. Green, Henry Joseph Kersting, 29 Clive Street, Calcutta, India: (or care of Messrs. J. B. Barry and Son, 110 Cannon Street, London, E.C.)

1893. Green, William Penrose, Messrs. Thomas Green and Son, Smithfield Iron Works, Leeds.

1895. Greensmith, James Eades, General Manager, Portland Locomotive and Car Works, Portland, Maine, United States.

1878. Greenwood, Arthur, Messrs. Greenwood and Batley, Albion Works, Leeds.

1874. Greenwood, William Henry (*Life Member*), Birmingham Small Arms and Metal Co., Adderley Park Works, Birmingham.

1894. Gregory, Horace Mark, Messrs. Brown, Lenox and Co., 9 Martin's Lane, Cannon Street, London, E.C.

1879. Grenville, Robert Neville, Butleigh Court, Glastonbury.

1892. Gresham, Harry Edward, Messrs. Gresham and Craven, Craven Iron Works, Salford, Manchester. [*Brake, Manchester.* 613.]

1880. Gresham, James, Messrs. Gresham and Craven, Craven Iron Works, Salford, Manchester. [*Brake, Manchester.* 613.]

1883. Grew, Frederick, Halton, 90 Ritherdon Road, Upper Tooting, London, S.W.

1874. Grew, Nathaniel, Dashwood House, 9 New Broad Street, London, E.C.

1895. Griffith, Percy, 55 Parliament Street, Westminster, S.W.

1895. Griffiths, Harry Denis, P.O. Box 455, Johannesburg, Transvaal, South Africa.

1884. Griffiths, James E., Messrs. Griffiths and James, 2 Bute Crescent, Cardiff.

1873. Griffiths, John Alfred, Edgar Street, East Brisbane, Queensland: (or care of Thomas Griffiths, Langham Road, Bowdon, near Altrincham.)

1889. Grimshaw, James Walter, Resident Engineer, Harbours and Rivers Department, Sydney, New South Wales; and Australian Club, Sydney, New South Wales.

1891. Groom, Richard Alfred, Shropshire Works, Wellington, Salop.

1879. Grose, Arthur, Messrs. Grose Norman and Co., Reliance Works, Northampton.

1886. Grove, David, 24 Friedrich Strasse, Berlin.

1884. Gulland, James Ker, Diamond Drill Co., 8 Victoria Street, Westminster, S.W. [*Gulland, London.*]

1870. Gwynne, James Eglinton Anderson (*Life Member*), Brooke Street Works, Holborn, London, E.C. [*Gwynnegram, London.*]

1870. Gwynne, John, Hammersmith Iron Works, Hammersmith, London, W.; and 89 Cannon Street, London, E.C.

1888. Hadfield, Robert Abbott, Hecla Foundry Steel Works, Sheffield. [*Hadfield, Sheffield.*]

1894. Haigh, Noel Newall, Messrs. W. B. Haigh and Co., Globe Iron Works, Plane Street, Oldham.

1884. Hall, Albert Francis, George F. Blake Manufacturing Co., 111 Federal Street, Boston; and 3 Cordis Street, Charlestown, Boston, Massachusetts, United States.

1892. Hall, George Edward, Mechanical Superintendent, Lighting Department, Salford Corporation, Wilburn Street, Salford, Manchester.

1894. Hall, Henry Platt, Messrs. Platt Brothers and Co., Hartford New Works, Oldham.

1879. Hall, John Francis, Norbury, Pittsmoor, Sheffield.

1881. Hall, John Percy, Carville, Lawrie Park Road, Sydenham, London, S.E.

1882. Hall, John Willim, Ivy House, Bilston.

1890. Hall, Oscar Standring, Messrs. Robert Hall and Sons, Hope Foundry, Bury, Lancashire.

1874. Hall, Thomas Bernard, 119 Colmore Row, Birmingham; and Ingleside, Sandon Road, Edgbaston, Birmingham. [*Tamar, Birmingham.*]

1871. Hall, William Silver, 9A Tsukiji, Tokyo, Japan: (or care of Messrs. Takata and Co., 88 Bishopsgate Street Within, London, E.C.)

1889. Hall-Brown, Ebenezer, Messrs. Hall-Brown Buttery and Co., Helen Street Engine Works, Govan, Glasgow. [*Triple, Glasgow.* 1843.]

1880. Hallett, John Harry, 123 Bute Street, Cardiff. [*Consulting, Cardiff.*]

1871. Halpin, Druitt, 17 Victoria Street, Westminster, S.W. [*Halpin, London.* 3075, care of Victoria Chambers Co.]

1895. Halstead, John Henry, Locomotive Superintendent, Ferro-Carril de Taltal, Taltal, Chili.

1894. Hamer, Walter, Messrs. Dobson and Barlow, Kay Street Machine Works, Bolton. [*Dobsons, Bolton.*]

1894. Hamilton, Robert, Park Villa, Institution Hill, Singapore, Straits Settlements.

1875. Hammond, Walter John, The Grange, Knockholt, near Sevenoaks.

1886. Hanbury, John James, Edgeley, Walm Lane, Willesden Park, London, N.W.

1896. Handyside, Charles Baird, Messrs. Waterlow and Sons, Finsbury, London, E.C.

1892. Hansell, Robert Blackwell, Tenth Street, Walbrook, Baltimore, Maryland, United States: (or care of James Hansell, 62 Jerningham Road, New Cross, London, S.E.)

1891. Harcourt, Otto Simon Henry, Clarence Iron Works, Leeds.

1894. Harding, James Cooper, Messrs. T. Richardson and Sons, Hartlepool Engine Works, Hartlepool.

1888. Harding, Thomas Walter, Tower Works, Leeds.

1874. Harding, William Bishop, X Ker. Szapary-utcza 21 sz., Budapest, Hungary.

1881. Hardingham, George Gatton Melhuish, 191 Fleet Street, London, E.C. [*Hardingham, London.*]

1883. Hardy, John George, 13 Riemergasse, Stadt, Vienna.

1869. Harfield, William Horatio, Arundel House, Thames Embankment, London, W.C. [*Harfield, London.*]

1887. Hargraves, Richard, 8 Rock Mount, Blackburn.

1887. Hargreaves, John Henry, Messrs. Hick Hargreaves and Co., Soho Iron Works, Crook Street, Bolton.

1888. Harker, William, Messrs. Richard Schram and Co., Cannon Street House, London, E.C. [*Schram, London.*]

1894. Harmer, Oscar, Messrs. Alfred Herbert and Co., Coventry; and Hopedale, Spencer Park, Coventry.

1891. Harris, Gordon, Messrs. Merryweather and Sons, Fire-Engine Works, Greenwich Road, London, S.E.

1879. Harris, Henry Graham, Messrs. Bramwell and Harris, 5 Great George Street, Westminster, S.W. [*Wellbram, London.* 3060.]

1873. Harris, Richard Henry, 63 Queen Victoria Street, London, E.C.; and Oak Hill, Surbiton, R.O., near Kingston-on-Thames.

1877. Harris, William Wallington, Messrs. A. M. Perkins and Son, 6 Seaford Street, Regent Square, London, W.C.; and 24 Alexandra Villas, Hornsey Park, London, N.

1885. Harrison, Frederick Henry, Lincoln Malleable Iron Works, Lincoln. [*Malleable, Lincoln.*]

1888. Harrison, George, 35 Therapia Road, Honor Oak, London, S.E.

1889. Harrison, Captain Gilbert Harwood, R.E., War Office, Whitehall, London, S.W.

1885. Harrison, Joseph, Royal College of Science, Exhibition Road, South Kensington, London, S.W.

1891. Harrison, Joseph Hutchinson, Messrs. Howson and Harrison, 2 Exchange Place, Middlesbrough; and Clifford Villa, Coatham, Redcar.

1887. Harrison, Thomas Henry, Messrs. Davey Paxman and Co., 78 Queen Victoria Street, London. E.C.

1894. Harrison, William John, Locomotive Superintendent, Cia. Paulista, Rio Claro, São Paulo, Brazil; and 44 Bournemouth Road, Folkestone.

1890. Harrison, William Robert, Messrs. Harrison, Bilton and Sharp, Paragon Chambers, Hull. [*Valuation, Hull.* 375.]

1883. Hart, Frederick, 36 Prospect Street, Poughkeepsie, New York, United States.

1872. Hartnell, Wilson, Benson's Buildings, Park Row, Leeds.

1882. Harvey, Charles Randolph, Messrs. G. and A. Harvey, Albion Machine Works, Govan, near Glasgow.

1892. Harvey, Francis Haniel, Messrs. Harvey and Co., Hayle Foundry, Hayle. Cornwall.

1886. Harvey, John Boyd, North's Navigation Collieries, Tondû, near Bridgend, Glamorganshire.

1883. Harvey, Robert, 1 Palace Gate, London, W.

1878. Harwood, Robert, Soho Iron Works, Bolton.

1881. Haslam, Sir Alfred Seale, Union Foundry, Derby. [*Zero, Derby.*]

1885. Hatton, Robert James, Henley's Telegraph Works, North Woolwich, London, E.

1857. Haughton, S. Wilfred (*Life Member*), Greenbank, Carlow, Ireland.

1878. Haughton, Thomas, 110 Cannon Street, London, E.C. [*Haughnot, London.*]

1885. Haughton, Thomas James, East Africa; and care of Mrs. Haughton, Draycott, near Weston-super-Mare.

1892. Hawkins, Rupert Skelton, District Locomotive Superintendent, Indian Midland Railway, Jhansi, India.

1861. Hawkins, William Bailey, 39 Lombard Street, London, E.C.

1870. Hawksley, Charles, 30 Great George Street, Westminster, S.W.

1891. Hawksley, George William, Brightside Boiler and Engine Works, Savile Street East, Sheffield. [*Hawksley, Sheffield.* 337.]

1882. Hayes, Edward, Watling Works, Stony Stratford. [*Hayes, Stony Stratford.*]

1879. Hayes, John, 55 Steep Hill, Lincoln.

1880. Hayter, Harrison, 33 Great George Street, Westminster, S.W.

1885. Head, Archibald Potter, Messrs. Jeremiah Head and Son, 47 Victoria Street, Westminster, S.W. [*Principium, London.* 3237]; and Queen's Square, Middlesbrough.

1888. Head, Harold Ellershaw, 5 Ilchester Mansions, Kensington, London, W.

1869. Head, Jeremiah, Messrs. Jeremiah Head and Son, 47 Victoria Street, Westminster, S.W. [*Principium, London.* 3237.]; and Queen's Square, Middlesbrough.

1857. Healey, Edward Charles, 33 Norfolk Street, Strand, London, W.C.

1890. Heap, Ray Douglas Theodore, 21 Park Road, Wimbledon.

1872. Heap, William, 28 Chapel Street, Liverpool. [*Metal, Liverpool.* 809.]

1889. Heath, George Wilson, Messrs. Heath and Co., Observatory Works, Crayford, Kent.

1888. Heatly, Harry, Messrs. Heatly and Gresham, 7 Hastings Street, Calcutta, India [*Brake, Calcutta.*]: (or Ballygunge, West Hill Road, Wandsworth, London, S.W.)

1875. Heenan, Hammersley, Messrs. Heenan and Froude, Newton Heath Iron Works, near Manchester; and The Manor House, Wilmslow, near Manchester. [*Spherical, Newton Heath.*]

1895. Heinke, Edwin Harry Alfred, Locomotive Superintendent, La Guaira and Caracas Railway, Caracas, Venezuela: (or care of Miss F. Heinke, The College, Stoke Bishop, near Bristol.)

1879. Hele-Shaw, Henry Selby, LL.D., Professor of Engineering, University College, Liverpool.

1869. Henderson, David Marr, Engineer-in-Chief, Imperial Maritime Customs Service of China, Shanghai, China.

1891. Henderson, Thomas, 6 and 8 Trueman Street, Liverpool. [*Mechanical, Liverpool.* 2366.]

1888. Henning, Gustavus Charles, 726 Temple Court, 5 Beekman Street, New York, United States.

1879. Henriques, Cecil Quixam, Messrs. John H. Wilson and Co., 15 Victoria Street, Westminster, S.W. [*Drague, London.*]

1875. Hepburn, George, Redcross Chambers, Redcross Street, Liverpool. [*Hepburn, Liverpool.*]

1891. Hepburn, Thomas, Officiating Chief Mechanical Engineer, Small Arms Ammunition Factory, Kirkee, Poona, India.

1892. Herbert, Alfred, Machine-Tool Works, Coventry. [*Lathe, Coventry.* 52.]

1893. Herbert, Charles, 35 Queen Victoria Street, London, E.C. [*Mancunian, London.*]

1893. Herbert, George Henry, Messrs. Richard Hornsby and Sons, 75A Queen Victoria Street, London, E.C.

1894. Herman, Benjamin Richard, Messrs. B. R. Herman and Co., McLeod Road, Karachi, India. [*Herman, Karachi.* 47.]

1884. Hernu, Arthur Henry, 69 Victoria Street, Westminster, S.W.

1894. Herriot, William Scott, 187 Osmaston Road, Derby.

1884. Hervey, Matthew Wilson, Assistant Engineer, West Middlesex Water Works, Hammersmith, London, W.

1879. Hesketh, Everard, Messrs. J. and E. Hall, Iron Works, Dartford. [*Hesketh, Dartford.*]

1872. Hewlett, Alfred, Haseley Manor, Warwick.

1887. Hibbert, George, Hibbert's Works, Bank Road, Gateshead.

1885. Hicken, Thomas, La Compañia Fabricantes Ingleses, 302 Calle Balcarce, Buenos Aires, Argentine Republic: (or care of Miss Hicken, Bourton, near Rugby.)

1896. Higby, Robert George, Sitarampur, Bengal, India.

1894. Higginbottom, Lloyd, Messrs. Higginbottom and Mannock, Crown Iron Works, West Gorton, Manchester.

1879. Higson, Jacob, Mining Engineer, Crown Buildings, 18 Booth Street, Manchester.

1883. Hill, John Kershaw, Engineer and Manager, West Surrey Water Works, High Street, Walton-on-Thames.

1885. Hill, Robert Anderson, Royal Mint, Little Tower Hill, London, E.

1890. Hiller, Edward George, Chief Engineer, National Boiler Insurance Co., 22 St. Ann's Square, Manchester.

1882. Hiller, Henry, Consulting Engineer, National Boiler Insurance Co., 22 St. Ann's Square, Manchester; and Athelney, Stanley Road, Alexandra Park, Manchester.

1873. Hilton, Franklin, 45 Talbot Street, Southport.

1887. Hindson, William, South Shore Engineering Works, Gateshead. [*Hindson, Gateshead.*]

1896. Hitchcock, Cyril, District Locomotive Superintendent, North Western Railway, Lahore, Punjaub, India.

1891. Hodge, Arthur, Belle Vue Terrace, St. Austell.

1891. Hodges, Frank Grattidge, Locomotive Department, Midland Railway, Burton-on-Trent.

1896. Hodges, Marcus Henry, Messrs. Hodges Brothers, City Basin Iron Works, Exeter.

1870. Hodges, Petronius, 101 Burngreave Road, Pitsmoor, Sheffield.

1880. Hodgson, Charles, Messrs. Saxby and Farmer, Railway Signal Works, Canterbury Road, Kilburn, London, N.W. [*Signalmen, London.* 7068.]

1889. Hodgson, George Herbert, Thornton Road, Bradford.

1892. Hodgson, Henry Edwin, Brookhouse Iron Works, Cleckheaton, S.O., Yorkshire.

1891. Hogarth, Thomas Oswald, Great Western Railway Works, Swindon.

1889. Hoggins, Alfred Farquharson, Knaresborough House, Collingham Place, South Kensington, London, S.W.

1866. Holcroft, Thomas, Bilston Foundry, Bilston.

1886. Holden, James, Locomotive Superintendent, Great Eastern Railway, Stratford Works, London, E.

1895. Holgate, Charles Henzell, School Close Works, Leeds.

1884. Holland, Calvert Bernard, Hazel Villa, Thicket Road, Anerley, London, S.E.

1895. Holliday, John, Messrs. A. Guinness, Son and Co., St. James' Gate Brewery, Dublin.

1886. Hollis, Charles William, Nottingham Engineering Co., St. Alban's Works, Radford, Nottingham. [*Iron, Nottingham.* 1578.]

1885. Hollis, Henry William, Whitworth House, Spennymoor.

1896. Holman, Frederick, Messrs. N. Holman and Sons, Penzance Foundry, Penzance.

1891. Holman, Hugh Wilson, Messrs. E. J. Caiger and Co., 77 Billiter Buildings, Billiter Street, London, E.C. [*Caiger, London.*]

1896. Holmes, Percy Frederick, Messrs. W. C. Holmes and Co., Whitestone Iron Works and Turnbridge Foundries, Huddersfield. [*Holmes, Huddersfield.* 113.]

1892. Holmström, Carl Albert, care of Swedish and Norwegian Consulate, Shanghai, China: (or care of Mrs. Holmström, Shirley, Kenton Road, Harrow.)

1883. Holroyd, John, 13 Alleyn Terrace, Park Road, West Dulwich, London, S.E.

1873. Holt, Henry Percy, 22 Chancery Lane, London, W.C.

1890. Holt, Robert, 2 Paper Buildings, The Temple, London, E.C.

1888. Homan, Harold, Messrs. Homan and Rodgers, 10 Marsden Street, Manchester. [*Namoh, Manchester.* 637.]

1895. Homfray, Samuel George, Sir W. G. Armstrong, Mitchell and Co., 8 Great George Street, Westminster, S.W.

1890. Hooker, Benjamin, Pear Tree Court, Farringdon Road, London, E.C.

1892. Hope, John Basil, Locomotive Department, North Eastern Railway, Leeds.

1866. Hopkins, John Satchell, Jesmond Grove, Highfield Road, Edgbaston, Birmingham.

1885. Hopkinson, Charles, Werneth Chambers, 29 Princess Street, Manchester.

1894. Hopkinson, Edward, D.Sc., Messrs. Mather and Platt, Salford Iron Works, Manchester.

1856. Hopkinson, John, Inglewood, St. Margaret's Road, Bowdon, near Altrincham.

1874. Hopkinson, John, Jun., D.Sc., F.R.S., 5 Victoria Street, Westminster, S.W. [3092.]

1877. Hopkinson, Joseph, Messrs. Joseph Hopkinson and Co., Britannia Works, Huddersfield.

1890. Hopper, Allan, Messrs. William Hopper and Co., Moscow, Russia.

1890. Hopper, James Russell, Messrs. William Hopper and Co., Moscow, Russia.

1889. Hopwood, John, Locomotive Superintendent, Argentine Great Western Railway, Mendoza, Argentine Republic.

1891. Hornbrook, Raymond Hillman, care of General Post Office, San Francisco, California.

1895. Horner, John, Clonard Foundry, Belfast.

1880. Hornsby, James, Messrs. Richard Hornsby and Sons, Spittlegate Iron Works, Grantham. [*Hornsbys, Grantham.*]

1889. Horsfield, Cooper, Messrs. Holroyd Horsfield and Wilson, Larchfield Foundry, Hunslet Road, Leeds.

1891. Horsfield, Ralph, Messrs. Ralph Horsfield and Co., Chapel-en-le-Frith, near Stockport.

1873. Horsley, Charles, 22 Wharf Road, City Road, London, N.

1892. Horsnell, Daniel, 79 Farringdon Road, London, E.C.

1868. Horton, Enoch, Alma Works, Darlaston, near Wednesbury.

1871. Horton, George, 4 Cedars Road, Clapham Common, London, S.W.

1886. Hosgood, John Howell, Locomotive and Hydraulic Superintendent, Barry Dock and Railways, Barry, near Cardiff.

1889. Hosken, Richard, Severn Tunnel Works, Sudbrook, near Chepstow.

1873. Hoskin, Richard, 8 Norfolk Street, Sheffield.

1892. Houghton, Francis Gassiot, 23 Tooting Bec Road, Tooting, London, S.W.

1866. Houghton, John Campbell Arthur, Calthorpe Road, Edgbaston, Birmingham.

1889. Houghton, Thomas Harry, 58 Pitt Street, Sydney, New South Wales: (or care of Messrs. James Simpson and Co., 101 Grosvenor Road, Pimlico, London, S.W.) [*Expansion, Sydney.*]

1887. Houghton-Brown, Ernest, Messrs. Houghton-Brown Brothers, Kingsbury Iron Works, Ballspond, London, N.

1896. House, Henry Alonzo, Bridgeport, Connecticut, United States.

1891. How, William Field, Mutual Life Buildings, George Street, Sydney, New South Wales. [*Alaska, Sydney.*]

1864. Howard, Eliot, Messrs. Hayward Tyler and Co., 90 Whitecross Street, London, E.C.

1879. Howard, James Harold, Britannia Iron Works, Bedford; and Kempston Grange, Bedford.

1882. Howard, John William, Gloucester Wagon Works, Gloucester.

1896. Howarth, Alfred Montgomery, Railway Construction Department, Public Works Office, Sydney, New South Wales.

1885. Howarth, William, Manager, Oldham Boiler Works, Oldham. [*Boilers, Oldham.*]

1861. Howell, Joseph Bennett, Messrs. Howell and Co., Brook Steel Works, Brookhill, Sheffield [*Howell, Sheffield.*]; and The Tower, Hathersage, near Sheffield.

1877. Howell, Samuel Earnshaw, Messrs. Howell and Co., Brook Steel Works, Brookhill, Sheffield. [*Howell, Sheffield.*]

1892. Howitt, James John, Messrs. Bowman Thompson and Co., Lostock Gralam, Northwich.

1882. Howl, Edmund, Messrs. Lee Howl and Co, Tipton. [*Howl, Tipton.*]

1877. Howlett, Francis, Messrs. Henry Clayton Son and Howlett, Atlas Works, Woodfield Road, Harrow Road, London, W. [*Brickpress, London.*]

1891. Hoy, Henry Albert, Locomotive Works, Lancashire and Yorkshire Railway, Horwich, near Bolton.

1887. Hoyle, James Rossiter, Messrs. Thomas Firth and Sons, Norfolk Works, Sheffield.

1891. Hubback, Charles Arbuthnot, 22 Church Crescent, St. Albans.

1882. Hudson, John George, Messrs. Hick Hargreaves and Co., Soho Iron Works, Crook Street, Bolton; and Glenholme, Bromley Cross, Bolton.

1884. Hudson, Robert, Gildersome Foundry, near Leeds [*Gildersome, Leeds.* 14.]; and Weetwood Mount, Headingley, near Leeds. [454.]

1893. Hudson, William, Ahmedabad, Bombay, India.

1881. Hughes, Edward William Mackenzie, 16 Court Road, West Norwood, London, S.E.

1867. Hughes, George Douglas, Messrs. G. D. Hughes and Son, Queen's Foundry, London Road, Nottingham.

1889. Hughes, John, Messrs. Hughes and Lancaster, 47 Victoria Street, Westminster, S.W.

1891. Hughes, Robert M., care of Reginald D. Hughes, 27 St. Mary's Terrace, Paddington, London, W.

1892. Hullah, Arthur, Victoria Jubilee Technical Institute, Byculla, Bombay, India: (or care of Walter Hunter, 12 Chetwynd Terrace, Meadow Road, Leeds.)

1883. Hulse, Joseph Whitworth, Messrs. Hulse and Co., Ordsal Works, Regent Bridge, Salford, Manchester. [*Esluh, Manchester.*]

1864. Hulse, William Wilson, Ordsal Works, Regent Bridge, Salford, Manchester. [*Esluh, Manchester.*]

1890. Humphries, Edward Thomas, Wyre, Pershore.

1866. Humphrys, Robert Harry, Messrs. Humphrys Tennant and Co., Deptford Pier, London, S.E.

1894. Humpidge, James Dickerson, Messrs. Humpidge, Holborow and Co., Dudbridge Iron Works, Stroud, Gloucestershire [*Humpidge, Cainscross.*]; and Glengar, Frome Park Road, Stroud, Gloucestershire.

1856. Hunt, Thomas, Egerton Mount, Heaton Chapel, R.O., Stockport.

1889. Hunter, Charles Lafayette, Engineer, Bute Docks, Cardiff.

1886. Hunter, John, Messrs. Campbells and Hunter, Dolphin Foundry, Saynor Road, Hunslet, Leeds.

1877. Hunter, Walter, Messrs. Hunter and English, High Street, Bow, London, E. [*Venator, London.*]

1888. Huxley, George, 20 Mount Street, Manchester.

1885. Hyland, John Frank, Railway Contractor, São Carlos do Pinhal, Estado de São Paulo, Brazil: (or care of Messrs. Lewis and Hyland, New Rents, Ashford, Kent.)

1877. Imray, John, Messrs. Abel and Imray, 20 Southampton Buildings, London, W.C.

1882. Ingham, William, Assistant Engineer, National Boiler Insurance Co., 22 St. Ann's Square, Manchester.

1888. Ingleby, Joseph, 20 Mount Street, Manchester.

1883. Instone, Thomas, 146 Leadenhall House, Leadenhall Street, London, E.C.

1894. Iorns, Charles Risbec, Milton House, Gaskell Road, Altrincham.

1892. Irons, Thomas, Messrs. Hudson Brothers, Clyde Engineering Works, Granville, New South Wales.

1894. Irwin, Thomas F., Messrs. Irwin, Atkinson and Young, 2A Tower Chambers, Old Church Yard, Liverpool. [*Irwall, Liverpool.* 2399.]

1895. Isaac, Robert, Messrs. Owen, Isaac and Owen, Union Iron Works, Portmadoc. [*Isaac, Portmadoc.*]

1887. Ivatt, Henry Alfred, Locomotive Engineer, Great Northern Railway, Doncaster.

1887. Ivatts, Lionel Edward, Hapetenea, Behobie, Basses-Pyrénées, France.

1884. Jacks, Thomas William Moseley, Patent Shaft Works, Wednesbury; and Woodgreen, Wednesbury.

1894. Jackson, John Broad, Messrs. Bentley and Jackson, Lodge Bank Works, Bury, Lancashire; and Knott End, Glebelands Road, Prestwich, Manchester.

1847. Jackson, Peter Rothwell, Salford Rolling Mills, Manchester; and Blackbrooke, Pontrilas, R.S.O., Herefordshire. [*Jacksons, Manchester.*]

1895. Jackson, Robert Cattley, Newcastle-on-Tyne Electric Supply Co., Pandon Dene, Newcastle-on-Tyne. [*Supply, Newcastle-on-Tyne.* 530.]

1873. Jackson, Samuel, C.I.E., 23 Calverley Park, Tunbridge Wells.

1886. Jackson, Thomas, 41 Wesley Road, Armley, Leeds.

1889. Jackson, William, Thorn Grove, Mannofield, Aberdeen.

1876. Jacobs, Charles Mattathias, 88 Bishopsgate Street Within, London, E.C. [*Vexillum, London.*]

1878. Jakeman, Christopher John Wallace, Manager, Messrs. Merryweather and Sons, Tram Locomotive Works, Greenwich Road, London, S.E.

1893. James, Arthur William, Calcutta Landing and Shipping Co., 24 Strand Road, Calcutta, India.

1889. James, Charles William, Gwynant, Avington Grove, Penge, London, S.E.

1895. James, Christopher William, Messrs. Joshua Buckton and Co., Well House Foundry, Meadow Road, Leeds.

1895. James, Enoch, Works Manager, Dowlais Iron Works, Cardiff.

1889. James, Reginald William, 1 Queen Victoria Street, London, E.C.

1879. Jameson, George, Glencormac, Bray, Ireland.

1881. Jameson, John, Messrs. Jameson and Schaeffer, Akenside Hill, Newcastle-on-Tyne. [*Jameson, Newcastle-on-Tyne.* 226.]

1888. Jaques, Captain William Henry, Messrs. See and Jaques, 1 Broadway, New York, United States. [*Menudeo, New York.*]

1888. Jeejeebhoy, Piroshaw Bomanjee, 17 Church Street, Bombay, India.

1880. Jefferies, John Robert, Messrs. Ransomes Sims and Jefferies, Orwell Works, Ipswich.

1881. Jefferiss, Thomas, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham. [*Tangyes, Birmingham.*]

1877. Jeffreys, Edward Homer, Hawkhills, Chapel Allerton, Leeds.

1893. Jenkin, Charles Frewen, Messrs. Nettlefolds, Castle Works, Tydu, near Newport, Monmouthshire.

1894. Jenkin, Thomas Henry, Messrs. J. Jamieson and Co., Queen's Dock Chambers, Hull. [*Propeller, Hull.* 94.]

1880. Jenkins, Rhys, Patent Office, 25 Southampton Buildings, London, W.C.

1892. Jenkins, William John, Messrs. W. J. Jenkins and Co., Beehive Works, Retford.

1896. Jenkinson, Thomas, Messrs. Pilkington Brothers, Plate Glass Works, St. Helen's, Lancashire.

1893. Jennins, Henry Horwood, Messrs. Edwin Oldroyd and Co., Crown Works, Leeds. [*Calorifics, Leeds.* 241.]

1878. Jensen, Peter, 77 Chancery Lane, London, W.C. [*Venture, London.*]

1889. Jessop, George, Messrs. Jessop and Appleby Brothers, London Steam-Crane and Engine Works, Leicester. [*Jessop, Leicester.*]

1885. Johnson, John Clarke, Messrs. James Russell and Sons, Crown Tube Works, Wednesbury.

1890. Johnson, John William, care of Baron L. Knoop, Maison du Banque des Marchands, Ilyinka, Moscow, Russia.

1891. Johnson, Lacey Robert, Master Mechanic, Pacific Division, Canadian Pacific Railway, Vancouver, British Columbia.

1888. Johnson, Lawrence Potter, District Locomotive Superintendent, Burma State Railway, Insein, Lower Burma; and 9 Blackheath Rise, Lewisham, London, S.E.

1882. Johnson, Samuel, Manager, Globe Cotton and Woollen Machine Works, Rochdale; and Glebelands, Rochdale.

1887. Johnson, Samuel Henry, Engineering Works, Carpenter's Road, Stratford, London, E.; and The Warren Hill, Loughton, Essex.

1861. Johnson, Samuel Waite, Locomotive Superintendent, Midland Railway, Derby.

1888. Johnson, William, Castleton Foundry and Engineering Works, Armley Road, Leeds.

1891. Johnston, Andrew, Bank Buildings, Hong Kong, China.

1896. Johnston, James, Chief Engineer, Brighton Corporation Water Works, 12 Bond Street, Brighton. [140.]

1895. Johnstone, Captain James Henry L'Estrange, R.E., Horse Guards, Whitehall, London, S.W.

1872. Joicey, Jacob Gowland, Messrs. J. and G. Joicey and Co., Forth Banks West Factory, Newcastle-on-Tyne. [*Engines, Newcastle-on-Tyne.*]

1882. Jolin, Philip, 35 Narrow Wine Street, Bristol; and 2 Elmdale Road, Redland, Bristol.

1891. Jones, Charles Frederick, 85 Davenport Street, Bolton.

1871. Jones, Charles Henry, Assistant Locomotive Superintendent, Midland Railway, Derby.

1873. Jones, Edward, Broomfield House, Perry Barr, Birmingham.

1884. Jones, Felix, Messrs. Jones and Foster, 39 Bloomsbury Street, Birmingham.

1878. Jones, Frederick Robert, Superintending Engineer, Sirmoor State, Nahan, near Umballa, Punjaub, India: (or care of Messrs. Richard W. Jones and Co., Newport, Monmouthshire.)

1867. Jones, George Edward, District Locomotive Superintendent, North Western Railway, Quetta, Beluchistan, India: (or care of Mrs. Edward Jones, Homelea, All Saints' Villas, Cheltenham.)

1878. Jones, Harry Edward, Engineer, Commercial Gas Works, Stepney, London, E.

1881. Jones, Herbert Edward, District Locomotive Superintendent, Midland Railway, Manchester.

1890. Jones, Morlais Glasfryn, 6 Delahay Street, Westminster, S.W.

1882. Jones, Samuel Gilbert, Hatherley Court, Gloucester.

1887. Jones, Thomas, Central Board School, Deansgate, Manchester.

1872. Jones, William Richard Sumption, Whitehall Court, London, S.W.

1883. Jordan, Edward, Manager, Cardiff Junction Dry Dock and Engineering Works, Cardiff.

1891. Jordan, Henry George, Jun., Municipal Technical School, Princess Street, Manchester.

1880. Joy, David, 85 Gracechurch Street, London, E.C.; and 118 Broadhurst Gardens, West Hampstead, London, N.W.

1891. Judd, Joseph Henry, Head Master, Municipal Technical School, York Place, Brighton.

1878. Jüngermann, Carl, Maschinenbau Actien Gesellschaft Vulcan, Bredow bei Stettin, Germany.

1884. Justice, Howard Rudulph, 55 and 56 Chancery Lane, London, W.C. [*Syng, London.* 65003.]

1889. Kanthack, Ralph, 18 Berners Street, London, W.

1888. Kapteyn, Albert, Westinghouse Brake Co., Canal Road, York Road, King's Cross, London, N.

1869. Keen, Arthur, London Works, near Birmingham. [*Globe, Birmingham.*]

1883. Keen, Francis Watkins, Patent Nut and Bolt Works, Westbromwich.

1873. Kelson, Frederick Colthurst, Angra Bank, Waterloo Park, Waterloo, near Liverpool.

1881. Kendal, Ramsey, Locomotive Department, North Eastern Railway, Darlington.

1879. Kennedy, Professor Alexander Blackie William, LL.D., F.R.S., 17 Victoria Street, Westminster, S.W. [*Kinematic, London.*]

1863. Kennedy, John Pitt, Bombay Baroda and Central Indian Railway, 45 Finsbury Circus, London, E.C.; and 29 Lupus Street, St. George's Square, London, S.W.

1892. Kennedy, Thomas, The Glenfield Engineering Works, Kilmarnock.

1875. Kenrick, George Hamilton, Messrs. A. Kenrick and Sons, Spon Lane, Westbromwich; and Whetstone, Somerset Road, Edgbaston, Birmingham.

1892. Kensington, Frederick, 2 Copthall Buildings, London, E.C.

1866. Kershaw, John, Marazion, St. Leonard's-on-Sea.

1884. Kershaw, Thomas Edward, Chilvers Coton Foundry, Nuneaton.

1890. Key, George Andrew, 27 Kirk Wynd, Kirkcaldy.

1885. Keyworth, Thomas Egerton, Ferro Carril Buenos Aires y Rosario, Campana, Buenos Aires, Argentine Republic: (or care of J. R. H. Keyworth, 28 Grosvenor Road, Birkenhead.)

1885. Kidd, Hector, Colonial Sugar Refining Co., Sydney, New South Wales.

1894. Kiernan, George, Manager, Messrs. Gresham and Craven, Craven Iron Works, Salford, Manchester.

1888. Kikuchi, Kyozo, Superintendent Engineer, Hirano Spinning Mill, Osaka, Japan.

1895. King, Charles Penrose, Resident Engineer, Epsom Water Works, Epsom.

1895. King, Thomas Scott, Works Manager, Messrs. Clench and Co., Lincoln Works, Chesterfield.

1872. King, William, Engineer, Liverpool United Gas Works, Duke Street, Liverpool.

1893. Kinghorn, John Warden, care of Messrs. Jardine Matheson and Co., Hong Kong, China.

1889. Kirby, Frank Eugene, 555 Woodward Avenue, Detroit, Michigan, United States.

1877. Kirk, Henry, Messrs. Kirk Brothers and Co., New Yard Iron Works, Workington. [*Kirks, Workington.*]

1884. Kirkaldy, John, 40 West India Dock Road, London, E. [*Compactum, London.*]

1875. Kirkwood, James, Chief Inspector of Machinery for Pei Yang Squadron; care of Commissioner of Customs, Kowloon, Hong Kong, China: (or Grange Park, Prestwick, Ayrshire.)

1864. Kirtley, William, Locomotive Superintendent, London Chatham and Dover Railway, Longhedge Works, Wandsworth Road, London, S.W. [3005.]

1859. Kitson, Sir James, Bart., M.P., Monk Bridge Iron Works, Leeds.

1868. Kitson, John Hawthorn, Airedale Foundry, Leeds. [*Airedale, Leeds.*]

1874. Klein, Thorvald, 50 Southbrook Road, Lee, London, S.E.

1889. Knap, Conrad, 11 Queen Victoria Street, London, E.C.

1891. Knight, Bertrand Thornton, Post Office, Perth, Western Australia: (or care of Major Knight, Swansea.)

1886. Knight, Charles Albert, Babcock and Wilcox Co., 21 Bothwell Street, Glasgow.

1890. Knight, James Percy, Kaiser Steam Tug Co., 27 Great Tower Street, London, E.C. [*Longboat, London.* 11,203.]

1896. Kwang, Kwong Yung, Linsi Colliery; care of the Chinese Engineering and Mining Co., Tientsin, North China.

1881. Laing, Arthur, Deptford Shipbuilding Yard, Sunderland.

1872. Laird, William, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead. [*Laird, Birkenhead.* 4003.]

1883. Lake, William Robert, 45 Southampton Buildings, London, W.C. [*Scopo, London.*]

1896. Lane, Francis Lawrence, Works Manager, Leeds Forge, Leeds.

1881. Langdon, William, Woodside, Salcombe, near Kingsbridge.

1881. Lange, Frederick Montague Townshend, 53 bis Boulevard de la Liberté, Lille (Nord), France.

1893. Langford, William, Messrs. W. M. Ward and Co., Limerick Foundry, Great Bridge, Tipton.

1879. Lapage, Richard Herbert, Oakfield, Langley Avenue, Surbiton, London, S.W.

1890. Last, Lieutenant Arthur John, R.A., Inspector of Ordnance Machinery, Mauritius.

1888. Latham, Baldwin, 13 Victoria Street, Westminster, S.W.; and Duppas House, Old Town, Croydon.

1890. Laurie, Leonard George, Mill Parade, Newport, Monmouthshire.

1867. Lawrence, Henry, The Grange Iron Works, Durham.

1893. Lawrie, James, Assistant Government Marine Surveyor, Singapore, Straits Settlements.

1874. Laws, William George, Borough Engineer and Town Surveyor, Town Hall, Newcastle-on-Tyne; and 65 Osborne Road, Newcastle-on-Tyne. [*Engineer, Newcastle-on-Tyne.*]

1882. Lawson, Frederick William, Messrs. Samuel Lawson and Sons, Hope Foundry, Leeds.

1870. Layborn, Daniel, Messrs. Daniel Layborn and Co., Dutton Street, Liverpool.

1883. Laycock, William S., Victoria Street Works, Sheffield; and Ranmoor, Sheffield. [*Invention, Sheffield.* 907.]

1860. Lea, Henry, Messrs. Henry Lea and Thornbery, 38 Bennett's Hill, Birmingham. [*Engineer, Birmingham.* 113.]

1892. Lea, Richard Henry, Stoke Green, Coventry.

1895. Lea, William Arthur, 5 Bedford Road, Toronto, Ontario, Canada.

1889. Leaf, Henry Meredith, Burlington Lodge, Streatham Common, London, S.W.

1883. Leavitt, Erasmus Darwin, Jun., 604 Main Street, Cambridgeport, Massachusetts, United States.

1890. Ledingham, John Machray, Royal Laboratory, Royal Arsenal, Woolwich.

1887. Lee, Cuthbert Ridley, Messrs. J. Coates and Co., Suffolk House, Laurence Pountney Hill, London, E.C.

1862. Lee, J. C. Frank, 6 Great Winchester Street, London, E.C.

1892. Lee, Richard John, Messrs. Harrison Lee and Sons, City Foundry, Limerick.

1890. Lee, Samuel Edward, Messrs. Harrison Lee and Sons, City Foundry, Limerick.

1863. Lees, Samuel, Messrs. H. Lees and Sons, Park Bridge Iron Works, Ashton-under-Lyne.

1889. Legros, Lucien Alphonse, 57 Brook Green, Hammersmith, London, W.

1896. Leisse, George Charles, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1883. Leslie, Joseph, 3 Canal Street, North Road, Entally, Calcutta, India.

1878. Lewis, Gilbert, 538 Eccles New Road, Eccles, Manchester.

1884. Lewis, Henry Watkin, Llwyn-yr-eos, Abercanaid, near Merthyr Tydfil.

1895. Lewis, Herbert William, Acting Senior Inspector of Boilers, Custom House, Bombay, India.

1884. Lewis, Sir William Thomas, Bart., Bute Mineral Estate Office, Aberdare; and Mardy, Aberdare.

1894. Liebert, Henry Anton, Messrs. John Holroyd and Co., Tomlinson Street, Hulme, Manchester.

1880. Lightfoot, Thomas Bell, Cornwall Buildings, 35 Queen Victoria Street, London, E.C. [*Separator, London.*]; and 7 Eastcombe Villas, Charlton Road, Blackheath, London, S.E.

1891. Lindsay, William Robertson, 1 Lorne Terrace, Forfar Road, Dundee.

1890. Lineham, Wilfrid James, Professor of Engineering and Mechanical Science, The Goldsmiths' Institute, New Cross, London, S.E.; and Jesmond, Leyland Road, Lee, London, S.E.

1856. Linn, Alexander Grainger, 121 Upper Parliament Street, Liverpool.

1876. Lishman, Thomas, Mining Engineer, Hetton Colliery, near Fence Houses.

1881. List, John, Superintendent Engineer, Messrs. Donald Currie and Co., Orchard Works, Blackwall, London, E.; and 3 St. John's Park, Blackheath, London, S.E.

1890. Lister, Robert Ramsbottom, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1866. Little, George, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham; and Colliston, Park Road, Southport.

1890. Livens, Frederick Howard, Messrs. Ruston Proctor and Co., Sheaf Iron Works, Lincoln.

1895. Livingston, James, 30 Great St. Helen's, London, E.C. [*Cinerary, London.*]

1886. Livsey, John Edward, Demonstrator in Mechanics and Mathematics, Royal College of Science, Exhibition Road, South Kensington, London, S.W.

1867. Lloyd, Charles, 73 Boundary Road, St. John's Wood, London, N.W.

1854. Lloyd, George Braithwaite (*Life Member*), Edgbaston Grove, Birmingham.

1882. Lloyd, Robert Samuel, Messrs. Hayward Tyler and Co., 90 Whitecross Street, London, E.C.

1894. Lloyd, Sampson Zachary, Managing Director, Engineering Department, Messrs. Nettlefolds, Birmingham [*Nettlefolds, Birmingham.*]; and Areley Hall, Stourport.

1879. Lockhart, William Stronach, 67 Granville Park, Blackheath, London, S.E.

1884. Logan, Andrew Linton, Railway Signal Works, Worcester.

1890. Logan, John Walker, Messrs. Davey Paxman and Co., Standard Iron Works, Colchester; and P.O. Box 2037, Johannesburg, Transvaal, South Africa.

1883. Logan, Robert Patrick Tredennick, Engineer's Office, Great Northern Railway of Ireland, Dundalk.

1884. Longbottom, Luke, Locomotive Carriage and Wagon Superintendent, North Staffordshire Railway, Stoke-on-Trent.

1894. Longridge, Captain Cecil Clement, 15 George Street, Mansion House, London, E.C.

1880. Longridge, Michael, Chief Engineer, Engine and Boiler Insurance Co., 12 King Street, Manchester.

1856. Longridge, Robert Bewick, Managing Director, Engine and Boiler Insurance Co., 12 King Street, Manchester; and Yew Tree House, Tabley, near Knutsford.

1875. Longridge, Robert Charles, Kilrie, Knutsford.

1880. Longworth, Daniel, 11 Avenue Victor Hugo, Place de l'Étoile, Paris.

1887. Lorrain, James Grieve, Norfolk House, Norfolk Street, London, W.C. [*Lorrain, London.*]

1888. Low, David Allan, Professor of Engineering, East London Technical College, People's Palace, Mile End Road, London, E.

1885. Low, Robert, Powis Lodge, Vicarage Park, Plumstead.

1884. Lowcock, Arthur, Coleham Foundry, Shrewsbury.

1884. Lowdon, John, General Manager, Barry Graving Dock and Engineering Co., Exchange Buildings, Cardiff. [*Bardock, Cardiff.*]

1891. Lowdon, Thomas, Kingsland Crescent, Barry Docks, B.O., near Cardiff.

1873. Lowe, John Edgar, Messrs. Bolling and Lowe, 2 Laurence Pountney Hill, London, E.C. [*Bird, London.* 1530.]

1873. Lucas, Arthur, 27 Bruton Street, New Bond Street, London, W.

1889. Lucy, Arthur John, Meadowcroft, Penn Road, Croydon.

1886. Lucy, William Theodore, care of Frank Hudson, Central Uruguay Railway, Monte Video, Uruguay: (or Thornleigh, Woodstock Road, Oxford.)

1895. Lumsden, Thomas Templeton Mackie, Managing Director, Messrs. James Milne and Son, Milton House Works, Edinburgh.

1877. Lupton, Arnold, Professor of Mining Engineering, Yorkshire College, Leeds; and 6 De Grey Road, Leeds. [*Arnold Lupton, Leeds.* 330.]

1887. Lupton, Kenneth, Messrs. K. and H. Lupton, Well Street, Coventry. [*Luptons, Coventry.* 77.]

1878. Lynde, James Henry, Buckland, Ashton-on-Mersey, near Manchester.

1889. Macallan, George, Works Manager, Great Eastern Railway, Stratford Works, London, E.

1892. Macbean, John James, Messrs. Howarth Erskine and Co., Singapore, Straits Settlements.

1888. Macbeth, John Bruce King, 44 Tamarind Lane, Bombay, India: (or care of Norman Macbeth, Heaton, Bolton.)

1883. Macbeth, Norman, Messrs. John and Edward Wood, Victoria Foundry, Bolton.

1884. MacCarthy, Samuel, Messrs. Lloyd and Lloyd, 90 Cannon Street, London, E.C.; and 18 Adelaide Road, Brockley, London, S.E.

1877. MacColl, Hector, Strandtown, Belfast.

1889. Macdonald, James Alexander, Broad Oaks Iron Works, Chesterfield.

1895. MacGarvey, Howard, Lombard Street Works, Dublin.

1892. Machado, Dr. Antonio Augusto, Manager, Companhia Metropolitana, Engineering and Boiler Works, Bahia, Brazil: (or care of Messrs. Heuser Humble and Co., 1 Fowkes Buildings, Great Tower Street, London, E.C.)

1892. Mackay, Charles O'Keefe, Locomotive Department, Lancashire and Yorkshire Railway, Horwich, near Bolton.

1890. Mackay, Joseph, Bangkok Dock Co., Bangkok, Siam: (or care of Messrs. John Birch and Co., 10 Queen Street Place, London, E.C.) [*Mackay, Bangkok.*]

1885. Mackenzie, John William, Messrs. Wheatley and Mackenzie, 40 Chancery Lane, London, W.C.; and Northfield, Oxford Road, Upper Teddington, S.O., Middlesex.

1894. Mackie, John, Reading Iron Works, Reading. [*Engineering, Reading.*]

1875. Maclagan, Robert, Blantyre, British Central Africa: (or care of Dr. Maclagan, 9 Cadogan Place, Belgrave Square, London, S.W.)

1889. MacLay, Alexander, Professor of Mechanical Engineering, Glasgow and West of Scotland Technical College, 38 Bath Street, Glasgow.

1886. MacLean, Alexander Scott, Messrs. Alexander Scott and Sons, Sugar Refinery, Berry-yards, Greenock; and 31 Bank Street, Greenock.

1877. MacLellan, John A., Messrs. Alley and MacLellan, Sentinel Works, Polmadie Road, Glasgow. [*Alley, Glasgow.* 673.]

1864. Macnab, Archibald Francis, Tokyo, Japan.

1884. Macpherson, Alexander Sinclair, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds.

1892. Mactear, James, F.R.S.E., 28 Victoria Street, Westminster, S.W. [*Celestine, London.* 3066.]

1879. Maginnis, James Porter, 9 Carteret Street, Queen Anne's Gate, Westminster, S.W. [*Offsett, London.*]

1891. Mahon, Major Reginald Henry, R.A., Superintendent, H. M. Shell Factory, Cossipore, Calcutta, India.

1896. Main, William Henderson, Superintendent, Engine Department, H. M. Mint, Bombay, India.

1873. Mair-Rumley, John George (*Life Member*), Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W. [*Aquosity, London.*]; and 43 Palace Court, London, W.

1884. Mais, Henry Coathupe, 2 Prell's Buildings, Collins and Queen Streets, Melbourne, Victoria.

1883. Malan, Ernest de Mérindol, Westinghouse Brake Co., York Road, King's Cross, London, N.

1879. Malcolm, Bowman, Locomotive Engineer, Belfast and Northern Counties Railway, Belfast.

1891. Manisty, Edward, Dundalk Iron Works, Dundalk, Ireland; and 24A Bryanston Square, London, W.

1894. Mann, James Hutchinson, Messrs. Mann and Charlesworth, Canning Works, Dewsbury Road, Leeds. [*Canning, Leeds.* 1335.]

1888. Mano, Bunji, Professor of Mechanical Engineering, Imperial University, Tokyo, Japan.

1875. Mansergh, James, 5 Victoria Street, Westminster, S.W.

1894. Mansfield, Edwin, Messrs. Edwin Mansfield and Sons, 140 Great Clowes Street, Broughton, Manchester. [*Gaslight, Manchester.*]

1891. Manson, James, Locomotive Superintendent, Glasgow and South Western Railway, Kilmarnock.

1862. Mappin, Sir Frederick Thorpe, Bart., M.P., Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield; and Thornbury, Sheffield.

1878. Marié, Georges, 4 Boulevard des Sablons, Neuilly-sur-Seine, France.

1891. Marks, Edward Charles Robert, 13 Temple Street, Birmingham.

1888. Marks, George Croydon, 13 Temple Street, Birmingham. [*Pumps, Birmingham.*]

1896. Markwick, Alfred Ernest, Mechanical Engineer to Karachi Municipality, Lawrence Road, Karachi, India.

1884. Marquand, Augustus John, 2 Dock Chambers, Bute Docks, Cardiff. [*Martial, Cardiff.*]

1887. Marriott, William, Engineer and Locomotive Superintendent, Midland and Great Northern Joint Railways, Melton Constable, Norfolk.

1887. Marsden, Benjamin, Messrs. S. Marsden and Son, Screw-Bolt and Nut Works, London Road, Manchester.

1896. Marsh, Douglas Earle, Locomotive Department, Great Northern Railway, Doncaster.

1871. Marsh, Henry William, Winterbourne, near Bristol.

1875. Marshall, Rev. Alfred (*Life Member*), The Vicarage, Feckenham, Redditch.

1865. Marshall, Francis Carr, Messrs. R. and W. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.

1890. Marshall, Frank Herbert, Blenheim Villa, Grove Hill, Middlesbrough.

1885. Marshall, Henry Dickenson, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough. [*Marshalls, Gainsborough.* 6648.]

1871. Marshall, James, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough. [*Marshalls, Gainsborough.* 6648.]

1885. Marshall, Jenner Guest, Messrs. Chance Brothers and Co., Glass Works, near Birmingham; and Westcott Barton Manor, Oxfordshire.

1877. Marshall, William Bayley, Richmond Hill, Edgbaston, Birmingham. [*Augustus, Birmingham.*]

1847. Marshall, William Prime, Richmond Hill, Edgbaston, Birmingham. [*Augustus, Birmingham.*]

1859. Marten, Edward Bindon, Pedmore, Stourbridge. [*Marten, Stourbridge.* 8504.]

1881. Martin, Edward Pritchard, Dowlais Iron Works, Dowlais.

1888. Martin, Henry James, 29 Bryn-y-mor Road, Swansea.

1889. Martin, The Hon. James, Messrs. James Martin and Co., Phœnix Foundry, Gawler, South Australia: (or care of J. C. Lanyon, 27 Gresham House, Old Broad Street, London, E.C.)

1892. Martin, Thomas George, Messrs. James McGowan and Co., Wapping Wall, London, E.

1886. Martin, William Hamilton, Engineering Manager, The Scheldt Royal Shipbuilding and Engineering Works, Flushing, Holland.

1882. Martindale, Warine Ben Hay, 38 Parliament Street, Westminster, S.W.; and Roveoaks, Ingatestone, Essex.

1882. Masefield, Robert, 14 Markham Square, Chelsea, London, S.W.

1884. Massey, George, Post Office Chambers, Pitt Street, Sydney, New South Wales.

1890. Massey, Stephen, Messrs. B. and S. Massey, Openshaw, Manchester.

1893. Massey, William Henry, 25 Queen Anne's Gate, Westminster, S.W.; and Twyford, R.S.O., Berkshire.

1892. Masterton, John Fraser, Locomotive Department, South Eastern Railway, Ashford, Kent.

1894. Mather, George Radford, Messrs. G. R. Mather and Son, Albion Foundry, Wellingborough. [*Mather, Wellingborough.*]

1867. Mather, William, Messrs. Mather and Platt, Salford Iron Works, Manchester. [*Mather, Manchester.*]

1883. Mather, William Penn, Queen Dyeing Co., Providence, Rhode Island, United States.

1882. Matheson, Henry Cripps, Enfield, Sunny Gardens, Hendon, London, N.W.

1891. Mathewson, Jeremiah Eugene, Tilghman's Sand-Blast Co., Broadheath, near Manchester.

1886. Matthews, Robert, Parrs House, Heaton Mersey, near Manchester.

1895. Matthews, Thomas, Imperial Iron Works, West Gorton, Manchester.

1853. Maudslay, Henry (*Life Member*), Westminster Palace Hotel, 4 Victoria Street, Westminster, S.W.: (or care of John Barnard, 47 Lincoln's Inn Fields, London, W.C.)

1893. Maunsell, Richard Edward Lloyd, Assistant Locomotive Engineer, Great Southern and Western Railway, Inchicore Works, near Dublin.

1873. Maw, William Henry, 35 Bedford Street, Strand, London, W.C. [3663.]

1884. Maxim, Hiram Stevens, Maxim Nordenfelt Guns and Ammunition Co., 32 Victoria Street, Westminster, S.W.; and 18 Queen's Gate Place, South Kensington, London, S.W.

1859. Maylor, William, Chesterleigh, Albemarle Road, Beckenham.

1874. McClean, Frank, Norfolk House, Norfolk Street, Strand, London, W.C.

1891. McCredie, Arthur Latimer, 250 Pitt Street, Sydney, New South Wales. [*Ebony, Sydney*. 63.]

1892. McDonald, John, Locomotive Works, Imperial Government Railways, Tokyo, Japan.

1878. McDonald, John Alexander, Assistant Engineer-in-chief, Public Works Department, Perth, Western Australia: (or care of James E. McDonald, 4 Chapel Street, Cripplegate, London, E.C.)

1865. McDonnell, Alexander, 23 Denbigh Street, London, S.W.; and Rydens, Hersham Road, Walton-on-Thames.

1891. McFarlane, George, Sun Insurance Buildings, 121 West George Street, Glasgow. [*Dunsloy, Glasgow*. 3777.]

1895. McFarlane, James, 10A Spring Gardens, Abbeyhill, Edinburgh.

1895. McGee, Walter, Albion Works, Stoney Brae, Paisley. [137.]

1892. McGregor, Peter (*Life Member*), Imperial Maritime Customs, Kowloon, Hong Kong, China.

1889. McIntyre, John Henry A., Lecturer on Mechanical Engineering, Allan Glen's School, Glasgow.

1880. McLachlan, John, Messrs. Bow McLachlan and Co., Thistle Engine Works, Paisley. [*Bow, Paisley.*]

1888. McLaren, Henry, Messrs. J. and H. McLaren, Midland Engine Works, Leeds.

1882. McLaren, Raynes Lauder, 10 Lammas Park Gardens, Ealing, London, W.

1888. McLarty, Farquhar Matheson, Messrs. McLarty and Co., 10 Patrick Street, Greenock.

1885. McNeil, John, Messrs. Aitken McNeil and Co., Helen Street, Govan, Glasgow. [*Colonial, Glasgow.*]

1896. McPherson, Stewart, Manager, Barnagore Jute Works, Calcutta, India.

1894. McQueen, John, Messrs. John Hetherington and Sons, Vulcan Works, Pollard Street, Manchester.

1891. Meade, Thomas de Courcy, Town Hall, Manchester; and Kenmore, Didsbury, Manchester.

1882. Meats, John Tempest, Mason Machine Works, Taunton, Massachusetts, United States.

1881. Meik, Charles Scott, care of P. Walter Meik, 16 Victoria Street, Westminster, S.W.

1858. Meik, Thomas, 13 Newbattle Terrace, Edinburgh.

1887. Melhuish, Frederick, Assistant Engineer, Southwark and Vauxhall Water Works, Southwark Bridge Road, London, S.E.

1891. Melville, William Charles, Superintendent Engineer, Liverpool Steam Tug Co., 44 Chapel Street, Liverpool.

1888. Melville, William Wilkie, Messrs. Caddy and Co., Daybrook, Nottingham.

1878. Menier, Henri, 56 Rue de Châteaudun, Paris.

1876. Menzies, William, Messrs. Menzies and Co., 50 Side, Newcastle-on-Tyne. [*William Menzies, Newcastle-on-Tyne. G.P.O.* 200. *Nor. Dis.* 1144.]

1894. Merrick, Robert, Warren's Place Iron Works, Cork.

1896. Merrifield, Leonard Lancaster, Suffolk House, Laurence Pountney Hill, London, E.C.

1875. Merryweather, James Compton, Messrs. Merryweather and Sons, Fire-Engine Works, Greenwich Road, London, S.E.; and 63 Long Acre, London, W.C. [*Merryweather, London.*]

1891. Metcalfe, Frederick Spencer, Pumping Station, Sewage Works, Burton-on-Trent.

1881. Meysey-Thompson, Arthur Herbert, Messrs. Hathorn Davey and Co., Sun Foundry, Dewsbury Road, Leeds.

1877. Michele, Vitale Domenico de, 14 Delahay Street, Westminster, S.W.; and Higham Hall, Rochester.

1884. Middleton, Reginald Empson, 17 Victoria Street, Westminster, S.W.

1891. Middleton, Robert, Sheepscar Foundry, Leeds.

1891. Middleton, Robert Thomas, Superintendent of Bridge Works, Bombay Baroda and Central India Railway, Bombay, India.

1862. Miers, Francis C., Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.; and Eden Cottage, West Wickham Road, Beckenham. [*Foundation, London.* 1920.]

1874. Milburn, John, Hawkshead Foundry, Quay Side, Workington.

1893. Millar, Jackson, Messrs. Riley Hargreaves and Co., 11 Merchant Road, Singapore, Straits Settlements: (or care of J. R. Allan, 93 Hope Street, Glasgow.)

1889. Miller, Adam, 50 Lime Street, London, E.C.

1885. Miller, Harry William, Princess Estate and Gold Mining Co., P.O. Box 1366, Johannesburg, Transvaal, South Africa.

1886. Miller, John Smith, Messrs. Smith Brothers and Co., Hyson Green Works, Nottingham.

1887. Miller, Thomas Lodwick, 7 Tower Buildings N., Water Street, Liverpool.

1893. Milligan, William Scott, Messrs. Pollit and Wigzell, Bank Foundry, Sowerby Bridge.

1893. Millington, Frederick Handel, Manager, Patent Pulp Manufacturing Co., Thetford; and Mill House, Thetford.

1885. Millis, Charles Thomas, Principal, Educational Department, Borough Road Polytechnic, London, S.E.

1887. Milne, William, Castle Buildings, West Street, Durban, Natal [*Metallic, Durban*]; and The Oaks, 52 Queen Street, Durban, Natal.

1892. Mitcheson, George Arthur, Longton, Staffordshire. [*Mitcheson, Longton.* 445.]

1870. Moberly, Charles Henry, 33 Bennett Park, Blackheath, London, S.E.

1896. Moffatt, Alexander Charles, Messrs. Moffatt and Eastmead, 39 Victoria Street, Westminster, S.W. [*Hoistway, London.*]

1885. Moir, James, Superintendent Engineer, Bombay Steam Navigation Co., Frere Road, Bombay.

1879. Molesworth, Sir Guilford Lindsay, K.C.I.E., The Manor House, Bexley, S.O., Kent.

1882. Molesworth, James Murray, Aberdeen House, Upper Holly Walk, Leamington.

1881. Molinos, Léon, 48 Rue de Provence, Paris.

1884. Monroe, Robert, Manager, Penarth Slipway and Engineering Works, Penarth Dock, Penarth.

1884. Moore, Benjamin Theophilus, Longwood, Bexley, S.O., Kent.

1876. Moore, Joseph, 1099 Adeline Street, Oakland, San Francisco, California: (or care of Ralph Moore, Government Inspector of Mines, 13 Clairmont Gardens, Glasgow.)

1895. Moore, William James Perry, Worthington Pumping Engine Co., 153 Queen Victoria Street, London, E.C.

1880. Moreland, Richard, Messrs. Richard Moreland and Son, 3 Old Street, St. Luke's, London, E.C. [*Expansion, London.*]

1889. Morgan, David John, 12 Windsor Road, Barry, near Cardiff.

1885. Morgan, Thomas Rees, Morgan Engineering Works, Alliance, Ohio, United States.

1887. Morison, Donald Barns, Messrs. T. Richardson and Sons, Hartlepool Engine Works, Hartlepool.

1896. Morley, Herbert William, Messrs. Cole, Marchent and Morley, Prospect Foundry, Bradford. [*Cole, Bradford.* 690.]

1895. Morrin, Richard, Superintendent Engineer, Messrs. Lamport and Holt, 21 Water Street, Liverpool.

1888. Morris, Charles, Messrs. Jessop and Co., Phœnix Iron Works, Calcutta, India.

1874. Morris, Edmund Legh, New River Water Works, Finsbury Park, London, N.

1890. Morris, Francis Sanders, 4 Trafalgar Square, London, W.C.

1890. Morris, John Alfred (*Life Member*), Empire Works, 78 Great Bridgewater Street, Manchester.

1892. Morton, David Home, 95 Bath Street, Glasgow.

1858. Mountain, Charles George, 35 Exchange Buildings, Stephenson Place, Birmingham.

1886. Mountain, William Charles, Messrs. Ernest Scott and Mountain, Close Works, Newcastle-on-Tyne [*Esco, Newcastle-on-Tyne.* 432.]; and 9 St. George's Terrace, Jesmond, Newcastle-on-Tyne.

1884. Mower, George A., Crosby Steam Gage and Valve Co., 75 Queen Victoria Street, London, E.C. [*Crosby, London.*]

1885. Mudd, Thomas, Manager, Central Marine Engine Works, West Hartlepool.

1873. Muir, Alfred, Messrs. William Muir and Co., Britannia Works, Sherbourne Street, Strangeways, Manchester.

1873. Muir, Edwin, 37 Brown Street, Manchester.

1876. Muirhead, Richard, Kentish Engineering Works, Maidstone. [*Muirhead, Maidstone.*]

1890. Müller, Henry Adolphus, Locomotive Superintendent, Municipal Railway, 3 North Road, Entally, Calcutta, India.

1890. Mumford, Charles Edward, St. Andrew's Works, Bury St. Edmunds.

1890. Munro, John, Professor of Mechanical Engineering, Merchant Venturers' Technical College, Unity Street, Bristol.

1890. Munro, Robert Douglas, Chief Engineer, Scottish Boiler Insurance and Engine Inspection Co., 13 Dundas Street, Glasgow.

1889. Münster, Bernard Adolph, Engineer, Yokohama, Japan.

1891. Murdoch, Robert Macmillan, Phœnix Metal Die and Engineering Co., 40 Coin Street, Stamford Street, London, S.E.

1890. Murray, Alexander John, Chief Mechanical Engineer, Government Gun-Powder Factory, Kirkee, Bombay, India.

1890. Murray, Kenneth Sutherland, Brin's Oxygen Works, 69 Horseferry Road, Westminster, S.W.

1894. Murray, Thomas Roberts, Messrs. L. Sterne and Co., Crown Iron Works, Glasgow.

1881. Musgrave, James, Messrs. John Musgrave and Sons, Globe Iron Works, Bolton. [*Musgrave, Bolton.*]

1882. Musgrave, Walter Martin, Messrs. John Musgrave and Sons, Globe Iron Works, Bolton. [*Musgrave, Bolton.*]

1888. Myers-Beswick, William Beswick (*Life Member*), 14 Victoria Street, Westminster, S.W.

1889. Nash, Thomas, Sheffield Testing Works, Blonk Street, Sheffield; and Guzerat House, Nether Edge, Sheffield.

1888. Nathan, Adolphus, Messrs. Larini Nathan and Co., Milan; and 15 Via Bigli, Milan, Italy.

1861. Naylor, John William, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds.

1883. Neate, Percy John, 16 The Banks, High Street, Rochester.

1889. Needham, Joseph Edward, Patent Office, 25 Southampton Buildings, London, W.C.

1892. Nelson, Arthur David, Hay and Lackey Streets, Sydney, New South Wales. [*Nelson, Sydney.* 160.]

1884. Nelson, John, Contractors' Office, Dringhouses, York.

1887. Nelson, Sidney Herbert, The Mill Cottage, Goring-on-Thames.

1881. Nesfield, Arthur, 14 Water Street, Liverpool.

1890. Newton, Percy, Vassall Lodge, Addison Road, Kensington, London, W.

1884. Nicholls, James Mayne, Locomotive Superintendent, Nitrate Railways, Iquique, Chili.

1884. Nicholson, Henry, care of G. H. Hill, Albert Chambers, Albert Square, Manchester.

1894. Nicholson, John Rumney, care of Messrs. Blackburn and Main, Solicitors, Carlisle.

1891. Nicholson, Thomas, Crownpoint Boiler Works, St. Marnock Street, Crownpoint Road, Glasgow.

1886. Noakes, Thomas Joseph, Messrs. Thomas Noakes and Sons, 35 and 37 Brick Lane, Whitechapel, London, E.

1884. Noakes, Walter Maplesden, 73 Clarence Street, Wynyard Square, Sydney, New South Wales.

1892. Norris, William, Pennington Motor Co., 5 and 6 Great Winchester Street, London, E.C.

1868. Norris, William Gregory, Coalbrookdale Iron Works, Coalbrookdale, Shropshire.

1883. North, Gamble, Pisagua, Chile: Queenswood, Eltham: (or 57 Gracechurch Street, London, E.C.)

1882. North, John Thomas, Messrs. North Humphrey and Dickenson, Engineering Works, Iquique, Chile; Woolpack Buildings, 3 Gracechurch Street, London, E.C.; and Avery House, Avery Hill, Eltham.

1878. Northcott, William Henry, General Engine and Boiler Co., Hatcham Iron Works, Pomeroy Street, New Cross Road, London, S.E.; and 7 St. Mary's Road, Peckham, London, S.E. [*Oxygen, London.* 8007.]

1888. Norton, William Eardley, 8 Great George Street, Westminster, S.W.

1885. Oakes, Sir Reginald Louis, Bart., Société Anonyme La Métallurgique, 1 Place de Louvain, Bruxelles, Belgium.

1887. O'Brien, Benjamin Thompson, 34 Catharine Street, Liverpool.

1887. O'Brien, John Owden, Messrs. W. P. Thompson and Co., Ducie Buildings, 6 Bank Street, Manchester.

1890. Ockendon, William, Messrs. John Brown and Co., Atlas Steel and Iron Works, Sheffield.

1868. O'Connor, Charles, 20 Lyra Road, Waterloo, Liverpool.

1888. O'Donnell, John Patrick, 70 and 71 Palace Chambers, 9 Bridge Street, Westminster, S.W.; and Fingal, Hemmelton Road, Bromley, Kent. [*ODonnell, London.* 3059.]

1889. Ogden, Fred, Patent Office, 25 Southampton Buildings, London, W.C.

1886. Ogle, Percy John, 4 Bishopsgate Street Within, London, E.C. [*Oglio, London.* 2463.]

1894. Oka, Saneyasu, 141, 1 Chome, Funakori Cho, Osaka, Japan.

1893. Oke, Francis Robert, 5 Coppenhall Terrace, Crewe. [*Oke, Crewe.*]

1875. Okes, John Charles Raymond, 63 Queen Victoria Street, London, E.C. [*Oaktree, London.*]

1882. Orange, James, Messrs. Danby Leigh and Orange, Hong Kong, China: (or care of Mrs. Mary Orange, 2 West End Terrace, Jersey.)

1885. Ormerod, Richard Oliver, 35 Philbeach Gardens, South Kensington, London, S.W.

1892. Osmond, Frederick John, The Tower, Bagot Street, Birmingham. [*Osmond, Birmingham.* 550.]

1867. Oughterson, George Blake, care of Peter Brotherhood, Belvedere Road, Lambeth, London, S.E.

1889. Owen, Thomas, Midland Railway, Derby.

1877. Panton, William Henry, Messrs. Dorman Long and Co., Middlesbrough.

1872. Parker, Thomas, Gorton House, Gorton, near Manchester.

1888. Parker, Thomas, Jun., Carriage and Wagon Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester; and Gorton House, Gorton, near Manchester.

1891. Parker, Thomas, F.R.S.E., Manor House, Tettenhall, Wolverhampton. [*Parker, Tettenhall.*]

1871. Parkes, Persehouse, 15 Sherbourne Terrace, Clarendon Street, Leamington Spa.

1895. Parkinson, Hudson Clough, Engineer's Office, Cumberland Basin, Bristol Docks, Bristol.

1884. Parlane, William, Manager, Hong Kong Ice Company, Hong Kong, China: (or Ladyton Cottage, Bonhill, Dumbartonshire.)

1892. Parratt, William Heather, Enmore Plantation, East Coast, Demerara, British Guiana.

1892. Parrott, Thomas Henry, Fairlight, Westfield Road, Edgbaston, Birmingham.

1886. Parry, Alfred, Messrs. Parry and Co., Vulcan Iron Works, Calcutta, India: (or care of Messrs. J. B. Barry and Son, 110 Cannon Street, London, E.C.)

1889. Parry, Evan Henry, care of Wolhuter Gold Mines, P. O. Box 860, Johannesburg, Transvaal, South Africa.

1878. Parsons, The Hon. Richard Clere, Messrs. Bateman Parsons and Bateman, 39 Victoria Street, Westminster, S.W. [*Outfall, London.* 3233.]; and 48 Prince's Gardens, London, S.W.

1886. Passmore, Frank Bailey, Suffolk House, 5 Laurence Pountney Hill, London, E.C. [*Knarf, London.*]

1896. Patchell, William Henry, Engineer-in-chief, Charing Cross and Strand Electricity Supply Corporation, 15 Maiden Lane, Covent Garden, London, W.C.

1880. Paterson, Walter Saunders, Bombay Burmah Trading Corporation, Rangoon, British Burmah, India: (or care of Messrs. Wallace Brothers, 8 Austin Friars, London, E.C.)

1877. Paton, John McClure Caldwell, Messrs. Manlove Alliott and Co., Bloomsgrove Works, Ilkeston Road, Nottingham. [*Manloves, Nottingham.*]

1891. Paton, Robert J., Companhia McHardy, Campinas, São Paulo, Brazil.

1881. Patterson, Anthony, Dowlais Iron Works, Cardiff; and 9 Glossop Terrace, Cardiff.

1883. Pattison, Giovanni, Messrs. C. and T. T. Pattison, Engineering Works, Naples. [*Pattison, Naples.*]

1891. Pattison, Joseph, 123 Bute Street, Cardiff.

1891. Paul, Matthew, Jun., Messrs. Matthew Paul and Co., Levenford Works, Dumbarton.

1891. Paulson, Scott, City Flour Mills, Cape Town, Cape Colony: (or care of Dr. Paulson, Mount Sorrel, near Loughborough.)

1872. Paxman, James Noah, Messrs. Davey Paxman and Co., Standard Iron Works, Colchester. [*Paxman, Colchester.*]

1880. Peache, James Courthope, 87 East Hill, Colchester.

1890. Peacock, Francis, Smyrna, Turkey in Asia.

1890. Peacock, James Albert Wells, Smyrna, Turkey in Asia.

1869. Peacock, Ralph, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1873. Pearce, Richard, Carriage and Wagon Superintendent, East Indian Railway, Howrah, Bengal, India.

1894. Pearce, Robert McLardy, care of National Bank of India, 47 Threadneedle Street, London, E.C.

1884. Pearson, Frank Henry, Earle's Shipbuilding and Engineering Works, Hull.

1885. Pearson, Henry William, Engineer, Bristol Water Works, Small Street, Bristol.

1870. Pearson, Thomas Henry, Moss Side Iron Works, Ince, near Wigan.

1888. Peel, Charles Edmund, Quay Parade, Swansea.

1873. Penn, John, M.P., Messrs. John Penn and Sons, Marine Engineers, Greenwich, London, S.E.

1873. Penn, William, Messrs. John Penn and Sons, Marine Engineers, Greenwich, London, S.E.

1874. Pepper, Joseph Ellershaw, Clarence Iron Works, Leeds.

1874. Percy, Cornelius McLeod, King Street, Wigan.

1893. Philip, William Littlejohn, Managing Director, Messrs. Spencer and Co., Melksham Foundry, Melksham.

1881. Philipson, John, Messrs. Atkinson and Philipson, Carriage Manufactory, 27 Pilgrim Street, Newcastle-on-Tyne. [*Carriage, Newcastle-on-Tyne.* 415.]

1885. Phillips, Charles David, Emlyn Engineering Works, Newport, Monmouthshire. [*Machinery, Newport, Mon.*]

1878. Phillips, John, 4 Corona Road, Burnt Ash Hill, Lee, London, S.E.

1885. Phillips, Lionel, Mining Engineer, Bultfontein Diamond Mine, Kimberley, South Africa; and care of H. Eckstein, Box 149, Johannesburg, Transvaal, South Africa.

1879. Phillips, Robert Edward, Royal Courts Chambers, 70 and 72 Chancery Lane, London, W.C.; and 47 Sussex Place, Onslow Gardens, London, S.W. [*Phicycle, London.*]

1890. Phillips, Walter, West India House, Leadenhall Street, London, E.C. [*Philology, London.*]

1882. Phipps, Christopher Edward, Locomotive Superintendent, Madras Railway, Perambore Works, Madras, India.

1894. Pickering, Jonathan, Resident Engineer, Colonial Sugar Refining Co., Sydney, New South Wales; and Broadwater, Richmond River, New South Wales: (or care of John Pickering, 1 Hillend Gardens, Partick Hill, Glasgow.)

1876. Piercy, Henry James Taylor, Messrs. Piercy and Co., Broad Street Engine Works, Birmingham. [*Piercy, Birmingham.* 20.]

1877. Pigot, Thomas Francis, 14 Fitzwilliam Place, Dublin.

1888. Pilkington, Herbert, Wellingborough Iron Works, Wellingborough.

1883. Pillow, Edward, Director of Technical Instruction for Norfolk, Shire Hall, Norwich; and 2 Carlton Terrace, Mill Hill Road, Norwich.

1892. Pinder, Charles Ralph, New Rietfontein Estate and Gold Mines, P. O. Box 897, Johannesburg, Transvaal, South Africa.

1892. Pirie, George, 7 Anglesea Road, Plumstead.

1882. Pirrie, John Sinclair, Austral Otis Elevator and Engineering Works, South Melbourne, Victoria: (or care of Messrs. John Birch and Co., 11 Queen Street Place, London, E.C.)

1888. Pirrie, William James, Messrs. Harland and Wolff, Belfast.

1883. Pitt, Walter, Messrs. Stothert and Pitt, Newark Foundry, Bath. [*Stothert, Bath.*]

1887. Place, John, Chief Engineer, Linotype Co., 188 Fleet Street, London, E.C.

1871. Platt, James, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester [*Atlas, Gloucester.*]; and Somerset House, Gloucester. [*Platt, Gloucester.*]

1883. Platt, James Edward, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1867. Platt, Samuel Radcliffe (*Life Member*), Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1878. Platts, John Joseph, Resident Engineer, Odessa Water Works, Odessa, Russia.

1869. Player, John (*Life Member*), Clydach Foundry, near Swansea.

1892. Pogson, Alfred Lee, Engineer-in-Chief, Harbour Trust Board and Works, Madras, India.

1888. Pogson, Joseph, Manager and Engineer, Huddersfield Corporation Tramways, Huddersfield.

1894. Poland, William, Messrs. William Poland and Co., King's Bench Walk, Southwark, London, S.E. [*Determine, London.*]

1893. Pollit, Edward Ernest, Messrs. Pollit and Wigzell, Bank Foundry, Sowerby Bridge.

1894. Pollitt, Harry, Chief Locomotive Engineer, Manchester Sheffield and Lincolnshire Railway, Gorton, Manchester. [*Traction, Gorton.*]

1886. Pollock, James, 22 Billiter Street, London, E.C. [*Specific, London.*]

1876. Pooley, Henry, Radnor Drive, Liscard, near Liverpool.

1890. Potter, William Henry, Brougham Chambers, Wheeler Gate, Nottingham.

1864. Potts, Benjamin Langford Foster, 55 Chancery Lane, London, W.C.; and 117 Camberwell Grove, London, S.E.

1878. Powel, Henry Coke, Tintern House, 64 Burnt Ash Hill, Lee, London, S.E.

1874. Powell, Thomas, Brynteg, Neath.

1891. Powles, Henry Handley Pridham, Faraday House, Charing Cross Road, London, W.C.

1867. Pratchitt, John, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.

1865. Pratchitt, William, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.

1892. Pratt, Middleton, 6 Richmond Terrace, New Brighton, near Birkenhead.

1885. Pratten, William John, Messrs. Harland and Wolff, Belfast.

1890. Preece, William Henry, C.B., F.R.S., General Post Office, St. Martin's-le-Grand, London, E.C.

1882. Presser, Ernest Charles Antoine, Barquillo 26, Madrid.

1877. Price, Henry Sherley, Messrs. Wheatley Kirk, Price, and Goulty, 49 Queen Victoria Street, London, E.C. [*Indices, London.*]

1896. Price, James, Harbour Engineer, 9 Lapp's Quay, Cork.

1866. Price, John, 6 Osborne Villas, Jesmond, Newcastle-on-Tyne.

1890. Price, John, Inspecting Engineer, Workington.

1889. Price, John Bennett, Messrs. Charles Macintosh and Co., Cambridge Street, Manchester; and Wyresdale, Wilbraham Road, Chorlton-cum-Hardy, near Manchester.

1859. Price-Williams, Richard, 32 Victoria Street, Westminster, S.W. [*Spandrel, London.*]

1886. Price-Williams, Seymour William, 5 Victoria Street, Westminster, S.W.

1895. Proctor, Charles Faraday, Fittings Department, Edison and Swan Co., Ponders End, London, N.

1894. Pryce, Henry James, Locomotive Superintendent, North London Railway, Bow Road Works, London, E.

1890. Pugh, Charles Henry, Whitworth Works, Rea Street South, Birmingham.

1887. Pullen, William Wade Fitzherbert, Fairley Villa, Oxford Road, Putney, London, S.W.

1884. Puplett, Samuel, 47 Victoria Street, Westminster, S.W.

1866. Putnam, William, Darlington Forge, Darlington.

1887. Pyne, Sir Thomas Salter, C.S.I., care of H.H. the Ameer of Afghanistan, Kabul: (or care of E. C. Clarke, Foreign Office, Government of India, Simla or Calcutta, India: or care of Edmund Neel, C.I.E., India Office, Whitehall, London, S.W.)

1892. Quentrall, Thomas, H.M. Inspector of Mines, Kimberley, South Africa.

1893. Quirk, Edward, Chief Mechanical Engineer, Trinity House, London, E.C.

1870. Radcliffe, William (*Life Member*), Camden House, 25 Collegiate Crescent, Sheffield.

1878. Radford, Richard Heber, 15 St. James' Row, Sheffield. [*Radford, Sheffield.*]

1868. Rafarel, Frederic William, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.

1884. Rafarel, William Claude, Barnstaple Foundry and Engineering Works, Victoria Road, Barnstaple. [*Rafarel, Barnstaple.*]

1885. Rainforth, William, Britannia Iron Works, Lincoln. [*Rainforths, Lincoln.*]

1878. Rait, Henry Milnes, Messrs. Rait and Gardiner, 155 Fenchurch Street, London, E.C. [*Repairs, London.*]

1892. Ramsay, William, Superintendent Engineer, Scottish Oriental Steamship Co., Hong Kong, China.

1847. Ramsbottom, John, Fernhill, Alderley Edge, Cheshire.

1894. Ramsbottom, John Goodfellow, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1860. Ransome, Allen, 304 King's Road, Chelsea, London, S.W. [*Ransome, London.*]

1886. Ransome, James Edward, Messrs. Ransomes Sims and Jefferies, Orwell Works, Ipswich. [*Ransomes, Ipswich.*]

1873. Rapier, Richard Christopher, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich; and 32 Victoria Street, Westminster, S.W. [*Ransomes Rapier, Westminster.*]

1888. Rapley, Frederick Harvey, Messrs. Taite and Carlton, 63 Queen Victoria Street, London, E.C.

1889. Ratcliffe, James Thomas, Baumwoll-Manufactur von Izr. K. Poznanski, Lodz, Russian Poland.

1883. Rathbone, Edgar Philip, South African Argosy Association, 18 Bishopsgate Street Within, London, E.C.

1867. Ratliffe, George, 7A Laurence Pountney Hill, London, E.C.

1893. Raven, Vincent Litchfield, Locomotive Department, North Eastern Railway, Darlington.

1872. Rawlins, John, Manager, Metropolitan Railway-Carriage and Wagon Works, Saltley, Birmingham [*Metro, Birmingham.*]; and The Mount, Erdington, near Birmingham.

1883. Reader, Reuben, Phœnix Works, Cremorne Street, Nottingham.

1887. Readhead, Robert, Messrs. John Readhead and Sons, West Docks, South Shields. [*Readhead, South Shields.* G.P.O. 14. Nat. 2024.]

1882. Reay, Thomas Purvis, Messrs. Kitson and Co., Airedale Foundry, Leeds.

1895. Redit, David, Downham Market, Norfolk.

1881. Redpath, Francis Robert, Canada Sugar Refinery, Montreal, Canada. [*Redpath, Montreal.*]

1883. Reed, Alexander Henry, 64 Mark Lane, London, E.C. [*Wagon, London.*]

1870. Reed, Sir Edward James, K.C.B., F.R.S., Broadway Chambers, Westminster, S.W. [*Carnage, London.*]

1894. Reed, Joseph William, Manager, Engine Works Department, Palmer's Shipbuilding and Iron Works, Jarrow.

1891. Reed, Thomas Alfred, Bute Docks, Cardiff. [*Steam, Cardiff.* 171.]

1891. Reid, Hugh (*Life Member*), Messrs. Neilson and Co., Hyde Park Locomotive Works, Glasgow.

1889. Rendell, Alan Wood, Locomotive Superintendent, East Indian Railway, Jamalpur, Bengal, India: (or 21A Goldhurst Terrace, South Hampstead, London, N.W.)

1890. Rendell, Samuel, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester; and New Mills, near Stockport.

1859. Rennie, George Banks, 20 Lowndes Street, Lowndes Square, London, S.W.

1879. Rennie, John Keith, 49 Queen's Gate, London, S.W.

1881. Rennoldson, Joseph Middleton, Marine Engine Works, South Shields. [*Rennoldson, South Shields.* 11.]

1876. Restler, James William, Engineer, Southwark and Vauxhall Water Works, Southwark Bridge Road, London, S.E.

1883. Reunert, Theodore (*Life Member*), Box 209, Kimberley, South Africa; Box 92, Johannesburg, Transvaal, South Africa: (or care of Messrs. Findlay, Durham and Brodie, 43–46 Threadneedle Street, London, E.C.)

1895. Rew, James Henry, Works Manager, Govan Tube Works, Helen Street, Govan, Glasgow.

1879. Reynolds, George Bernard, Manager, Warora Colliery, Warora, Central Provinces, India: (or care of Messrs. Grindlay and Co., 55 Parliament Street, Westminster, S.W.)

1890. Rice, Thomas Sydney, Aldermary House, 60 Watling Street, London, E.C. [*Ricto, London.*]

1866. Richards, Edward Windsor, Low Moor Iron Works, near Bradford.

1884. Richards, Lewis, Bedlinog Hall, Bedlinog, Treharris, R.S.O., Glamorganshire.

1895. Richardson, Andrew, Messrs. Campbell and Calderwood, Soho Engine Works, Paisley.

1892. Richardson, Harry Alfred, Messrs. Hick Hargreaves and Co., Soho Iron Works, Crook Street, Bolton.

1865. Richardson, John, Methley Park, near Leeds.

1873. Richardson, John, Messrs. Robey and Co., Globe Iron Works, Lincoln.

1891. Richardson, John Scott, Box 13, Royal Exchange, Glasgow: (or care of J. W. Champness Richardson, Lindum, 23 Coleridge Road, Crouch End, London, N.)

1887. Richardson, Thomas, M.P., Messrs. T. Richardson and Sons, Hartlepool Engine Works, Hartlepool.

1874. Riches, Tom Hurry, Locomotive Superintendent, Taff Vale Railway, Cardiff. [*Locomotive, Cardiff.*]

1873. Rickaby, Alfred Austin, Bloomfield Engine Works, Sunderland. [*Rickaby, Sunderland.*]

1879. Ridley, James Cartmell, Swalwell Steel Works, Newcastle-on-Tyne.

1893. Ridley, James Taylor, 6 Ruthin Gardens, Cardiff.

1887. Riekie, John, District Locomotive Superintendent, North Western Railway, Quetta, Beluchistan, India.

1874. Riley, James, General Manager, Glasgow Iron and Steel Company, 36 St. Vincent Place, Glasgow. [*Ingot, Glasgow.* 825.]

1894. Riley, Joseph Hacking, Elton Iron Works, Bury, Lancashire.

1885. Ripley, Philip Edward, Messrs. Ransomes Sims and Jefferies, Orwell Works, Ipswich.

1884. Ripper, William, Professor of Mechanical Engineering, The Technical School, St. George's Square, Sheffield.

1879. Rixom, Alfred John, 108 Park Road, Loughborough.

1891. Roberts, Hugh Jorwerth, Messrs. Burn and Co., Howrah Iron Works, Howrah, Calcutta, India: (or care of R. P. Roberts, 3 Osborne Road, Liscard, near Liverpool.)

1887. Roberts, Thomas, Locomotive Engineer, Government Railways, Adelaide, South Australia.

1879. Roberts, Thomas Herbert, Mechanical Superintendent, Chicago and Grand Trunk Railway, Detroit, Michigan, United States.

1887. Roberts, William, 13 Craven Hill Gardens, Hyde Park, London, W.

1879. Robertson, William, Newlyn, Eton Avenue, Hampstead, London, N.W.

1894. Robinson, Arthur Maurice, Messrs. Thomas Robinson and Son, Railway Works, Rochdale. [*Robinson, Rochdale.*]

1894. Robinson, Charles John, Messrs. Thomas Robinson and Son, Railway Works, Rochdale. [*Robinson, Rochdale.*]

1890. Robinson, Frederick Arthur, Messrs. F. A. Robinson and Co., 54 Old Broad Street, London, E.C. [*Farrago, London.*]

1874. Robinson, Henry, Professor of Civil Engineering, King's College, Strand, London, W.C.; and 13 Victoria Street, Westminster, S.W.

1895. Robinson, James, Messrs. T. Richardson and Sons, Hartlepool Engine Works, Hartlepool.

1859. Robinson, John, Messrs. Sharp Stewart and Co., Atlas Works, Glasgow; and Westwood Hall, near Leek.

1886. Robinson, John, 8 Vicarage Terrace, Kendal.

1878. Robinson, John Frederick, Messrs. Sharp Stewart and Co., Atlas Works, Glasgow. [*Loco, Glasgow.* 3210.]

1891. Robinson, John George, Locomotive and Carriage Engineer, Waterford and Limerick Railway, Limerick.

1892. Robinson, Leslie Stephen, 28 Victoria Street, Westminster, S.W. [*Eyebolts, London.*]

1894. Robinson, Mark Heaton, Messrs. Willans and Robinson, Ferry Works, Thames Ditton [*Willans, Thames-Ditton.*]; and Chatley, Fassett Road, Kingston-on-Thames.

1890. Robinson, Sydney Jessop, Messrs. W. Jessop and Sons, Brightside Steel Works, Sheffield.

1878. Robinson, Thomas Neild, Messrs. Thomas Robinson and Son, Railway Works, Rochdale. [*Robinson, Rochdale.*]

1895. Robinson, William, Professor of Mechanical and Electrical Engineering, University College, Nottingham.

1891. Roche, Francis James, care of W. F. Stock, Glenelg, South Australia.

1872. Rofe, Henry, 8 Victoria Street, Westminster, S.W.

1885. Rogers, Henry John, Watford Engineering Works, Watford. [*Mechanical, Watford.* 35.]

1892. Ronald, Henry, Small Arms Ammunition Factory, Dum Dum, near Calcutta, India.

1889. Rosenthal, James Hermann, Babcock and Wilcox Co., 147 Queen Victoria Street, London, E.C.

1881. Ross, William, Messrs. Ross and Walpole, North Wall Iron Works, Dublin. [*Iron, Dublin.* 311.]

1893. Rounthwaite, Henry Morrison, Messrs. Maudslay Sons and Field, 110 Westminster Bridge Road, London, S.E.; and 15 Nicosia Road, Wandsworth Common, London, S.W.

1856. Rouse, Frederick, Locomotive Department, Great Northern Railway, Peterborough.

1878. Routh, William Pole, Sutton Court, Sutton, Surrey.

1888. Rowan, James, Messrs. David Rowan and Son, Elliot Street, Glasgow.

1892. Rowe, Almond, Senior Government Marine Surveyor, Singapore, Straits Settlements.

1891. Rowland, Bartholomew Richmond, Messrs. Luke and Spencer, Broadheath, near Manchester.

1867. Ruston, Joseph, Messrs. Ruston Proctor and Co., Sheaf Iron Works, Lincoln; and 6 Onslow Gardens, South Kensington, London, S.W. [*Ruston, Lincoln.*]

1884. Rutherford, George, Managing Director, Mercantile Pontoon Co., Roath Dock, Cardiff. [*Mercantile, Cardiff.* G.P.O. 33; Nat. 30.]

1885. Ryan, John, D.Sc., Professor of Physics and Engineering, University College, Bristol.

1866. Ryland, Frederick, Messrs. A. Kenrick and Sons, Spon Lane, Westbromwich.

1866. Sacré, Alfred Louis, 60 Queen Victoria Street, London, E.C. [*Sextant, London.* 1668.]

1864. Saïd, Marshal M., Pasha, Engineer, Turkish Service, Constantinople: (or care of J. C. Frank Lee, 6 Great Winchester Street, London, E.C.)

1892. Sainsbury, Francis Charles Barrett, Chief Engineer, Messrs. John Jameson and Son, Bow Street Distillery, Dublin.

1859. Salt, George, 8 Welbeck Street, Cavendish Square, London, W.

1874. Sampson, James Lyons, Messrs. David Hart and Co., North London Iron Works, Wenlock Road, City Road, London, N. [*Bascule, London.* 6699.]

1865. Samuelson, The Right Hon. Sir Bernhard, Bart., F.R.S., Britannia Iron Works, Banbury; 56 Prince's Gate, South Kensington, London, S.W.; and Lupton, Brixham, South Devon.

1881. Samuelson, Ernest, Messrs. Samuelson and Co., Britannia Iron Works, Banbury.

1890. Sandberg, Christer Peter, 19 Great George Street, Westminster, S.W.

1881. Sanders, Henry Conrad, Messrs. H. G. Sanders and Son, Victoria Works, Victoria Gardens, Notting Hill Gate, London, W.; and Elm Lodge, Southall.

1871. Sanders, Richard David, Hartfield House, Eastbourne.

1886. Sandford, Horatio, Messrs. E. A. and H. Sandford, Thames Iron Works, Gravesend.

1881. Sandiford, Charles, Locomotive and Carriage Superintendent, North Western Railway, Lahore, Punjaub, India.

1891. Sands, Harold, Craythorne, Tenterden, Ashford, Kent.

1894. Sankey, Captain Matthew Henry Phineas Riall, Messrs. Willans and Robinson, Rugby.

1874. Sauvée, Albert, 22 Parliament Street, Westminster, S.W. [*Sovez, London.* 3133.]

1891. Savill, Arthur Slater, Exhaust Steam Injector Company, 4 St. Ann's Square, Manchester.

1880. Saxby, John, Messrs. Saxby and Farmer, Railway Signal Works, Canterbury Road, Kilburn, London, N.W. [*Signalmen, London.* 7068.]; and North Court, Hassocks, R.S.O., Sussex.

1893. Saxon, Alfred, Openshaw Engineering Works, Manchester. [*Saxons, Openshaw.* 959.]

1894. Saxon, George, Openshaw Engineering Works, Manchester. [*Saxons, Openshaw.* 959.]

1894. Saxon, James, Openshaw Engineering Works, Manchester. [*Saxons, Openshaw.* 959.]

1869. Scarlett, James, Messrs. E. Green and Son, 2 Exchange Street, Manchester; and Stamford Road, Bowdon, R.O., near Altrincham.

1890. Schofield, George Andrew, General Manager, Sicilian Railways, Palazzo Brijuccia, Palermo, Sicily: (or care of I. D. Schofield, Oakfield, Alderley Edge, Cheshire.)

1886. Scholes, William Henry, 1255 n/n Rivadavia, Buenos Aires, Argentine Republic: (or care of George Scholes, Orwell House, Upton Manor, Plaistow, London, E.)

1883. Schönheyder, William, 4 Rosebery Road, Brixton, London, S.W. [*Schönheyder, London.*]

1880. Schram, Richard, Cannon Street House, London, E.C. [*Schram, London.*]

1890. Schroller, William, 38 Claypath, Durham. [*Bulumatari, Durham.*]

1886. Schurr, Albert Ebenezer, Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.

1891. Scott, Arthur Forbes, 67 Swan Arcade, Bradford.

1882. Scott, Charles Herbert, Messrs. Summers and Scott, High Orchard Iron Works, Gloucester.

1890. Scott, Frederick McClure, 89 Victoria Street, Liverpool.

1891. Scott, F. Walter, Messrs. George Scott and Son, 44 and 46 Christian Street, London, E. [*Thirty-four, London.* 4390.]

1875. Scott, Frederick Whitaker, Atlas Steel and Iron Wire Rope Works, Reddish, Stockport. [*Atlas, Reddish.*]

1891. Scott, Henry John, Glendon Engine Works, Kettering. [*Engine, Kettering.*]

1881. Scott, James, care of Messrs. Reid and Acutt, Smith Street, Durban. Natal: (or Douglasfield, Murthly, Perthshire.)

1886. Scott, James, Consett Iron Works, Consett, R.S.O., County Durham.

1894. Scott, Robert, H. M. Mint, Calcutta, India.

1891. Scott, Robert Julian, Professor of Engineering, New Zealand University, Canterbury College, Christchurch, New Zealand.

1861. Scott, Walter Henry, Great Western of Brazil Railway, Pernambuco, Brazil: (or care of H. Eaton, 75 Tulse Hill, London, S.W.)

1896. Scriven, Charles, Leeds Old Foundry, Leeds.

1882. Seabrook, Alfred William, Engineer Surveyor to the Port of Bombay, Port Office, Bombay, India.

1892. Seaman, Charles Joseph, Stockton Forge Works, Stockton-on-Tees. [*Forge, Stockton-on-Tees.*]

1882. Seaton, Albert Edward, Earle's Shipbuilding and Engineering Works, Hull.

1891. Selby, Millin, 2 Rue du Lac, Bruxelles, Belgium.

1882. Selfe, Norman, 279 George Street, Sydney, New South Wales.

1884. Sellers, Coleman, E.D., Professor of Engineering, Stevens Institute, and Franklin Institute; 3301 Baring Street, Philadelphia, Pennsylvania, United States.

1865. Sellers, William, Pennsylvania Avenue, Philadelphia, Pennsylvania, United States.

1896. Sennett, Alfred Richard, The Chalet, Portinscale Road, Putney, London, S.W.

1894. Seymour, Louis Irving, Messrs. H. Eckstein and Co., P.O. Box 149, Johannesburg, Transvaal, South Africa.

1883. Shackleford, Arthur Lewis, General Manager, Britannia Railway-Carriage and Wagon Works, Saltley, Birmingham.

1884. Shackleford, William Copley, Manager, Lancaster Wagon Works, Lancaster; and 6 Victoria Street, Westminster, S.W.

1894. Shand, John, Heath Villa, Peterculter, Aberdeen.

1872. Shanks, Arthur, Fairmile, Cobham, Surrey.

1884. Shanks, William, Messrs. Thomas Shanks and Co., Johnstone, near Glasgow. [*Shanks, Johnstone.*]

1881. Shapton, William, Sir William G. Armstrong, Mitchell and Co., 8 Great George Street, Westminster, S.W.

1891. Sharp, Henry, 23 College Hill, London, E.C.; and 1 Whitehall Gardens, London, S.W.

1895. Sharp, John Hutchinson, Messrs. Sharp, Stewart and Co., Atlas Works, Glasgow.

1875. Sharp, Thomas Budworth, Consulting Engineer, Muntz Metal Works, Birmingham; and County Chambers A, Martineau Street, Birmingham. [*Budworth, Birmingham.*]

1881. Shaw, Joshua, Messrs. John Shaw and Sons, Wellington Street Works, Salford, Manchester.

1890. Sheldon, Harry Cecil, Messrs. Boult and Wade, 63 Long Row, Nottingham. [*Boult, Nottingham.* 645.]

1891. Shenton, James, Messrs. Tinker Shenton and Co., Hyde Boiler Works, Hyde, near Manchester.

1892. Shepherd, James, Messrs. Joshua Buckton and Co., Well House Foundry, Meadow Road, Leeds.

1861. Shepherd, John, 45 Regent Park Terrace, Headingley, Leeds.

1875. Sheppard, Herbert Gurney, Chief Engineer, Assioot-Girgeh Railway, Assioot, Upper Egypt: (or 89 Westbourne Terrace, Hyde Park, London, W.)

1876. Shield, Henry, Messrs. Fawcett Preston and Co., Phœnix Foundry, 17 York Street, Liverpool.

1888. Shin, Tsuneta, Director, Ishikawajima Shipbuilding and Engineering Co., Tokyo, Japan.

1892. Shirlaw, Andrew, Suffolk Works, Oozells Street, Birmingham. [*Shirlaw, Birmingham.*]

1889. Shone, Isaac, 47 Victoria Street, Westminster, S.W.

1890. Shoosmith, Harry, 52 Mark Lane, London, E.C.

1890. Shore, Alfred Thomas, Government Inspector of Steam Boilers, Custom House, Bombay, India.

1893. Shroff, Adurjee Burjorjee, Chief Engineer, Sassoon Spinning Mills, Bombay, India.

1885. Shuttleworth, Alfred, Messrs. Clayton and Shuttleworth, Stamp End Works, Lincoln. [*Claytons, Lincoln.*]

1885. Shuttleworth, Major Frank, Messrs. Clayton and Shuttleworth, Stamp End Works, Lincoln; and Old Warden Park, Biggleswade. [*Claytons, Lincoln.*]

1891. Siemens, Alexander (*Life Member*), 12 Queen Anne's Gate, Westminster, S.W.

1871. Simon, Henry, 20 Mount Street, Manchester. [*Reform, Manchester.*]

1877. Simonds, William Turner (*Life Member*), Messrs. J. C. Simonds and Son, Oil Mills, Boston.

1876. Simpson, Arthur Telford, Engineer, Chelsea Water Works, 38 Parliament Street, Westminster, S.W.

1883. Simpson, Charles Liddell, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W. [*Aquosity, London.*]

1885. Simpson, James Thomas, Executive Engineer, Henzada Division, Henzada, Burma.

1882. Simpson, John Harwood, 1 Hargwyne Street, Brixton, London, S.W.

1889. Sinclair, Nisbet, 11 Randolph Gardens, Crow Road, Partick, Glasgow.

1847. Sinclair, Robert, care of Messrs. Sinclair Hamilton and Co., 17 St. Helen's Place, Bishopsgate Street, London, E.C. [*Sinclair, London.*]

1891. Sinclair, Russell, Messrs. J. Wildridge and Sinclair, 97 Pitt Street, Sydney, New South Wales.

1881. Sisson, William, Quay Street Iron Works, Gloucester. [*Sisson, Gloucester.*]

1872. Slater, Alfred, Gloucester Wagon Works, Gloucester.

1892. Slight, George Henry, Sub-Director of Lighthouses, Valparaiso, Chile: (or care of George H. Slight, Sen., Brook Cottage, Ashburton, Devonshire.)

1885. Slight, William Hooper, Messrs. W. Henderson and Co., Soerabaya, Java: (or care of G. H. Slight, 64 Cromwell Road, Fitzhugh, Southampton.)

1891. Sloan, Robert Alexander, Messrs. Sloan and Lloyd Barnes, Castle Chambers, 26 Castle Street, Liverpool. [*Technical, Liverpool.*]

1886. Small, James Miln, Messrs. Urquhart and Small, 17 Victoria Street, Westminster, S.W.

1889. Smelt, John Dann, Argentine Great Western Railway, 4 Finsbury Circus, London, E.C.

1879. Smith, Charles Hubert, Board of Trade Surveyors' Office, Leith.

1860. Smith, Henry, Messrs. Hill and Smith, Brierley Hill Iron Works, Brierley Hill; and Summerhill, Kingswinford, near Dudley. [*Fencing, Brierley Hill.*]

1881. Smith, Henry, Messrs. Simpson and Co., 101 Grosvenor Road, Pimlico, London, S.W.

1860. Smith, Sir John, Parkfield, Duffield Road, Derby.

1876. Smith, John, Wintoun Terrace, Rochdale.

1893. Smith, John, Salford Works, Richard Street, Birmingham. [*Profiler, Birmingham.* 2540.]

1883. Smith, John Bagnold, Newstead Colliery, near Nottingham.

1891. Smith, John Reney, Messrs. Harvey and Bower, 16 Seaton Buildings, 17 Water Street, Liverpool. [*Inspecting, Liverpool.* 6204.]

1890. Smith, John Windle, Messrs. Thomas Drysdale and Co., 438 Calle Moreno, Buenos Aires, Argentine Republic: (or care of Edward Smith, The "Lock," Gainsborough.)

1870. Smith, Michael Holroyd, Royal Insurance Buildings, Crossley Street, Halifax; and 47 Victoria Street, Westminster, S.W. [*Outfall, London.*]

1886. Smith, Reginald Arthur, Messrs. Dorman and Smith, Ordsal Station Electrical Works, Salford, Manchester.

1881. Smith, Robert Henry, Professor of Engineering, Mason Science College, Birmingham; and 124 Hagley Road, Edgbaston, Birmingham.

1896. Smith, Roger Thomas, Compagnie Hydro-Électrique Anversoise, 8 Quai Cockerill, Antwerp, Belgium.

1885. Smith, Thomas, Steam Crane Works, Old Foundry, Rodley, near Leeds. [*Tomsmith, Leeds.*]

1890. Smith, Thomas Ridsdill, 10 Crown Terrace, Anlaby Road, Hull.

1881. Smith, Wasteneys, 59 Sandhill, Newcastle-on-Tyne. [*Wasteneys Smith, Newcastle-on-Tyne.* 429.]

1890. Smith, William, London and Manchester Plate Glass Co., Sutton, St. Helen's, Lancashire.

1894. Smith, William, Roads Bridges and Sewerage Department, Sewerage Construction Branch, Public Works Office, Sydney, New South Wales.

1863. Smith, William Ford, Messrs. Smith and Coventry, Gresley Iron Works, Ordsal Lane, Salford, Manchester. [*Gresley, Manchester.* 564.]

1887. Smith, William Mark, District Locomotive Carriage and Wagon Superintendent, Great Southern and Western Railway, Cork.

1884. Smyth, William Stopford, Engineer, Alexandra Docks, Newport, Monmouthshire.

1883. Snelus, George James, F.R.S., Ennerdale Hall, Frizington, near Carnforth.

1885. Snowdon, John Armstrong, Stanners Closes Steel Works, Wolsingham, near Darlington.

1895. Somers, Walter, Haywood Forge, Halesowen, near Birmingham.

1887. Sorabji, Shapurji, Messrs. Shapurjee and Ratanshaw, 1 and 2 West India House, Leadenhall Street, London, E.C.

1889. Souter-Robertson, David, Assistant Superintendent, Government Canal Foundry and Workshops, Roorkee, North Western Provinces, India.

1885. Southwell, Frederick Charles, Messrs. F. C. Southwell and Co., 41 Upper Thames Street, London, E.C.

1877. Soyres, Francis Johnstone de, 6 Oakfield Road, Clifton, Bristol.

1893. Spence, Arthur William, Manager, Cork Street Foundry and Engineering Works, Dublin.

1887. Spence, William, Cork Street Foundry and Engineering Works, Dublin.

1887. Spencer, Alexander, Messrs. George Spencer, Moulton and Co., 77 Cannon Street, London, E.C. [*George Spencer, London.*]

1878. Spencer, Alfred G., Messrs. George Spencer, Moulton and Co., 77 Cannon Street, London, E.C. [*George Spencer, London.*]

1896. Spencer, Charles James, 80 Queen Victoria Street, London, E.C.

1892. Spencer, Henry Bath, 91 Haworth's Buildings, Cross Street, Manchester. [*Concentration, Manchester.*]

1877. Spencer, John, Globe Tube Works, Wednesbury; and 14 Great St. Thomas Apostle, London, E.C. [*Tubes, Wednesbury. Tubes, London.* 6504.]

1867. Spencer, John W., Newburn Steel Works, Newcastle-on-Tyne. [*Newburn, Newcastle-on-Tyne.*]

1885. Spencer, Mountford, Messrs. Luke and Spencer, Broadheath, near Manchester; and The Hill, Teignmouth.

1854. Spencer, Thomas, Newburn Steel Works, Newcastle-on-Tyne. [*Newburn, Newcastle-on-Tyne.*]

1891. Spencer, William, Messrs. James Spencer and Co., Chamber Iron Works, Hollinwood, near Manchester.

1885. Spooner, George Percival, Locomotive Superintendent, Bolan Railway, Hirokh, Beluchistan, India; and 200 Portsdown Road, Maida Vale, London, W.

1883. Spooner, Henry John, 309 Regent Street, London, W.

1895. Sprague, Ernest Headly, Engineering Laboratory, University College, Gower Street, London, W.C.

1896. Spring, Francis Joseph Edward, C.I.E., Consulting Engineer to the Government of India for Railways, Shillong, Assam, India.

1869. Stabler, James, 13 Effra Road, Brixton, London, S.W.

1877. Stanger, George Hurst, Queen's Chambers, North Street, Wolverhampton.

1875. Stanger, William Harry, Chemical Laboratory and Testing Works, Broadway, Westminster, S.W. [3117.]

1888. Stanley, Harry Frank, Messrs. H. Pontifex and Sons, Farringdon Works, Shoe Lane, London, E.C.; and 84 Finsbury Park Road, London, N.

1888. Stannah, Joseph, 20 Southwark Bridge Road, London, S.E.

1884. Stanton, Frederic Barry, Mansion House Chambers, 11 Queen Victoria Street, London, E.C.

1874. Stephens, Michael, Chief Locomotive Superintendent of the Government Railways, Cape Town, Cape of Good Hope.

1868. Stephenson, George Robert, Ben Braich, Tilehurst Road, Reading.

1879. Stephenson, Joseph Gurdon Leycester, 6 Drapers' Gardens, London, E.C. [*Fluvius, London.*]

1888. Stephenson-Peach, William John, Askew Hill, Repton, Burton-on-Trent.

1876. Sterne, Louis, Messrs. L. Sterne and Co., Crown Iron Works, Glasgow [*Crown, Glasgow.*]; and 28 Victoria Street, Westminster, S.W. [*Elsterne, London.* 3066.]

1891. Stevens, James, 9 and 11 Fenchurch Avenue, London, E.C.

1894. Stevens, Thomas, 37 and 38 Mark Lane, London, E.C.

1887. Stevenson, David Alan, F.R.S.E., 84 George Street, Edinburgh.

1892. Stevinson, Thomas, The Nook, Nailsworth, near Stroud, Gloucestershire.

1893. Steward, George Richard, 15 Queen Street, Queen Victoria Street, London, E.C.

1887. Stewart, Andrew, 41 Oswald Street, Glasgow.

1878. Stewart, Duncan, Messrs. Duncan Stewart and Co., London Road Iron Works, Glasgow. [*Stewart, Glasgow.* 531.]

1851. Stewart, John, Blackwall Iron Works, Poplar, London, E. [*Steamships, London.*]; and Egerton Lodge, Queen's Road, Tunbridge Wells.

1888. Stiff, William Charles, 75 Hagley Road, Edgbaston, Birmingham.

1892. Still, William Henry, Hudjuff, Aden, Arabia.

1880. Stirling, James, Locomotive Superintendent, South Eastern Railway, Ashford, Kent.

1885. Stirling, Matthew, Locomotive Superintendent, Hull Barnsley and West Riding Junction Railway and Dock Co., Hull.

1896. Stirling, Patrick, Great Northern Railway, Doncaster.

1888. Stirling, Robert, Locomotive Department, North Eastern Railway, Gateshead.

1875. Stoker, Frederick William, 6 Consolidated Gold Fields Buildings, P.O. Box 353, Johannesburg, Transvaal, South Africa.

1892. Stone, Edward Herbert, Chief Engineer for Construction, East Indian Railway, Allahabad, India.

1887. Stone, Frank Holmes, G. P. O., Freetown, Sierra Leone.

1877. Stothert, George Kelson, Steam Ship Works, Bristol.

1888. Strachan, James, 70 Frederick Street, Gray's Inn Road, London, W.C.

1892. Strachan, John, Craigisla, Penylan, Cardiff.

1888. Straker, Sidney, Messrs. Straker Whitworth and Co., 139 Cannon Street London, E.C. [*Rhomboidal, London.*]; and Marazion, Bromley Hill, Kent.

1895. Stromeyer, Johann Philipp Edmond Charles, Lloyd's Register of British and Foreign Shipping, 342 Argyle Street, Glasgow.

1884. Stronge, Charles, Locomotive Department, Porto Alegre and New Hamburg Railway, São Leopoldo, Rio Grande do Sol, Brazil: (or 1 Albion Street, Hyde Park, London, W.)

1873. Strype, William George, 115 Grafton Street, Dublin. [*Strype, Dublin.*]

1890. Stutzer, Waldemar, Koltchugin Brass and Copper Mill Co., Alexandrov Station, Jaroslav Railroad, Russia.

1882. Sugden, Thomas, Babcock and Wilcox Co., 147 Queen Victoria Street, London, E.C.

1890. Sulzer, Jacob, Messrs. Sulzer Brothers, Winterthur, Switzerland.

1861. Sumner, William, 2 Brazennose Street, Manchester.

1875. Sutcliffe, Frederic John Ramsbottom, Engineer, Low Moor Iron Works, near Bradford.

1883. Sutton, Joseph Walker, 36 Bedford Street, Strand, London, W.C.

1880. Sutton, Thomas, Carriage and Wagon Superintendent, Furness Railway, Barrow-in-Furness.

1882. Swaine, John, 9 Miles Road, Clifton, Bristol.

1884. Swan, Joseph Wilson, F.R.S., 57 Holborn Viaduct, London, E.C.; and 58 Holland Park, London, W.

1882. Swinburne, Mark William, Wallsend Brass Works, Newcastle-on-Tyne; and 117 Park Road, Newcastle-on-Tyne. [*Bronze, Wallsend.*]

1864. Swindell, James Swindell Evers, Homer Hill, Cradley, Staffordshire.

1890. Swinerd, Edward, Westwood, 27 Waldegrave Road, Norwood, London, S.E.

1878. Taite, John Charles, Messrs. Taite and Carlton, 63 Queen Victoria Street, London, E.C. [1618.]; and The Corner House, Shortlands, S.O., Kent.

1875. Tangye, George, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham. [*Tangyes, Birmingham.*]

1889. Tangye, Harold Lincoln, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham.

1861. Tangye, James, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham; and Aviary Cottage, Illogan, near Redruth.

1895. Tannett, John Croysdale, Messrs. Fullerton, Hodgart and Barclay, Vulcan Works, Paisley.

1879. Tartt, William, Maythorn, Blindley Heath, Godstone, near Red Hill.

1893. Tasker, Frederick, Messrs. Tasker Sons and Co., New Station Road, Sheffield. [*Tasker, Sheffield.* 1005.]

1876. Taunton, Richard Hobbs, 10 Coleshill Street, Birmingham.

1874. Taylor, Arthur, Manager, Sociedad Anglo-Vasca, Villanueva del Duque, Provincia de Cordoba, Spain: (or 21 Victoria Road, Kensington, London, W.)

1873. Taylor, John, Midland Foundry, Queen's Road, Nottingham.

1875. Taylor, Joseph Samuel, Messrs. Taylor and Challen, Derwent Foundry, 60 and 62 Constitution Hill, Birmingham. [*Derwent, Birmingham.*]

1874. Taylor, Percyvale, Messrs. Burthe and Taylor, Paris; and 21 Victoria Road, Kensington, London, W.

1893. Taylor, Robert, Jun., Works Manager, Messrs. Asa Lees and Co., Soho Iron Works, Oldham.

1882. Taylor, Robert Henry, Garfield Lodge, Stoke, Devonport.

1896. Taylor, William Isaac, Messrs. Clarke, Chapman and Co., 50 Fenchurch Street, London, E.C.

1895. Tebbutt, Sidney, 32 Avenue Road, Leamington.

1864. Tennant, Sir Charles, Bart. (*Life Member*), The Glen, Innerleithen, near Edinburgh.

1882. Terry, Stephen Harding, 17 Victoria Street, Westminster, S.W.

1891. Tetlow, Ernest, Messrs. Tetlow Brothers, Bottoms Iron Works, Hollinwood, near Manchester.

1877. Thom, William, Messrs. Yates and Thom, Canal Foundry, Blackburn.

1889. Thomas, James Donnithorne, 25A Old Broad Street, London, E.C. [*Kooringa, London.*]

1896. Thomas, James Martin, Superintending Engineer, Boston and Dominion Lines of Steamers; 24 James Street, Liverpool.

1867. Thomas, Joseph Lee, 2 Hanover Terrace, Ladbroke Square, Notting Hill, London, W.

1888. Thomas, Philip Alexander, 35 Queen Victoria Street, London, E.C. [*Argument, London.*]

1864. Thomas, Thomas, 10 Richmond Road, Roath, Cardiff.

1874. Thomas, William Henry, 6 Delahay Street, Westminster, S.W.

1891. Thompson, James, Highfield Boiler Works, Ettingshall, Wolverhampton. [*Boiler, Wolverhampton.*]

1875. Thompson, John, Highfield Boiler Works, Ettingshall, Wolverhampton. [*Boiler, Wolverhampton.*]

1883. Thompson, Richard Charles, Messrs. Robert Thompson and Sons, Southwick Shipbuilding Yard, Sunderland.

1887. Thompson, William Phillips, 6 Lord Street, Liverpool.

1875. Thomson, James McIntyre, Glen Tower, Great Western Road, Glasgow.

1868. Thomson, John, 3 Crown Terrace, Dowanhill, Glasgow.

1889. Thomson, Robert McNider, Kobe Engine Works, Kobe, Japan: (or care of William Hipwell, Hillside House, Sharnbrook, Bedford.)

1893. Thornbery, William Henry, 38 Bennett's Hill, Birmingham. [*Engineer, Birmingham.* 113.]

1868. Thornewill, Robert, Messrs. Thornewill and Warham, Burton Iron Works, Burton-on-Trent.

1885. Thornley, George, Messrs. Buxton and Thornley, Waterloo Engineering Works, Burton-on-Trent.

1877. Thornton, Frederic William, Hull Hydraulic Power Co., Machell Street, Hull.

1882. Thornton, Hawthorn Robert, Lancashire and Yorkshire Railway, Horwich, near Bolton.

1876. Thornycroft, John Isaac, F.R.S., Messrs. John I. Thornycroft and Co., Steam Yacht and Launch Builders, Church Wharf, Chiswick, London, W. [*Thornycroft, London.*]

1882. Thow, William, Locomotive Engineer, New South Wales Government Railways, Eveleigh Workshops, Sydney, New South Wales: (or care of Joseph Meilbek, 13 Victoria Street, Westminster, S.W.)

1896. Tickner, Richard, District Locomotive Superintendent, North Western Railway, Karachi, India.

1891. Tilley, Albert, Glasgow Iron and Steel Co., Wishaw.

1885. Timmermans, François, Managing Director, Société anonyme des Ateliers de la Meuse, Liége, Belgium. [*Société Meuse, Liége.*]

1884. Timmis, Illius Augustus, 2 Great George Street, Westminster, S.W. [*Timmis, London.*]

1886. Tipping, Henry, 19 Gloucester Place, Greenwich, London, S.E.

1890. Titley, Arthur, Beechwood, Hartopp Road, Four Oaks, Sutton Coldfield, near Birmingham.

1888. Todd, Robert Ernest, Mechanical Engineer, Tucuman, Estacion Provincia, Argentine Republic: (or care of William H. Todd, County Buildings, Land of Green Ginger, Hull.)

1875. Tomkins, William Steele, Messrs. Sharp Stewart and Co., Atlas Works, Glasgow; and 28 Victoria Street, Westminster, S.W.

1896. Toone, William Carson, Messrs. Carson and Toone, Wiltshire Foundry, Warminster.

1888. Topple, Charles James, 6 Blendon Terrace, Plumstead Common.

1894. Touch, John Edward, 16 Fore Street Avenue, London, E.C.

1883. Tower, Beauchamp, 5 Queen Anne's Gate, Westminster, S.W.

1889. Towler, Alfred, Messrs. Hathorn Davey and Co., Sun Foundry, Leeds.

1893. Townsend, Major C. Collingwood, R.A., Superintendent, Gun-Carriage Factory, Madras, India.

1890. Trail, John, Marine Superintendent, Knott's Prince Line of Steamers, Newcastle-on-Tyne.

1888. Travis, Henry, Superintending Engineer and Constructor of Shipping to the War Department, Royal Arsenal, Woolwich.

1889. Treharne, Gwilym Alexander, Pontypridd; and Aberdare.

1889. Trenery, William Penrose, Poste Restante, Paris.

1883. Trentham, William Henry, 39 Victoria Street, Westminster, S.W.

1876. Trevithick, Richard Francis, Locomotive and Carriage Superintendent, Japanese Government Railways, Kobe, Japan: (or care of Mrs. Mary Trevithick, The Cliff, Penzance.)

1887. Trier, Frank, Messrs. Brunton and Trier, 19 Great George Street, Westminster, S.W.

1896. Trotter, Alexander Pelham, Government Electrician to Cape Colony, Cape Town, Cape Colony.

1885. Trueman, Thomas Brynalyn, 61 Calle Defensores de Buenos Aires, San Fernando, Buenos Aires, Argentine Republic: (or care of Thomas R. Trueman, 3 The Barons, Twickenham.)

1887. Turnbull, Alexander, Messrs. Alexander Turnbull and Co., St. Mungo Works, Bishopbriggs, Glasgow. [*Valve, Glasgow.* 1270.]

1885. Turnbull, John, Jun., 18 Blythswood Square, Glasgow. [*Turbine, Glasgow.* 59.]

1894. Turner, Albert, Whitehouse Machine Works, Denton, near Manchester. [*Machines, Denton.* 5.]

1866. Turner, Frederick, Messrs. E. R. and F. Turner, St. Peter's Iron Works, Ipswich. [*Gippeswyk, Ipswich.*]

1882. Turner, Thomas, Messrs. Andrew Barclay, Sons and Co., Caledonia Works, Kilmarnock. [*Barclayson, Kilmarnock.* 10.]

1886. Turner, Tom Newsum, Vulcan Iron Works, Langley Mill, near Nottingham.

1876. Turney, Sir John, Messrs. Turney Brothers, Trent Bridge Leather Works, Nottingham. [*Turney, Nottingham.*]

1882. Tweedy, John, Messrs. Wigham Richardson and Co., Newcastle-on-Tyne.

1856. Tyler, Sir Henry Whatley, K.C.B., Linden House, Highgate Road, London, N.W.

1889. Tyrrell, Joseph John, 33 Sewell's Walk, Lincoln.

1875. Urquhart, Thomas, Delny House, Delny, R.S.O., Ross-shire.

1880. Valon, William Andrew McIntosh, 140 and 141 Temple Chambers, Temple Avenue, London, E.C.; and Ramsgate. [*Valon, Ramsgate.*]

1895. Van Raalte, Joseph, General Manager, Royal Shipbuilding and Engineering Works, Flushing, Holland. [*Schelde, Flushing.*]

1885. Vaughan, William Henry, Royal Iron Works, West Gorton, Manchester. [*Vaunting, Manchester.* 5106.]

1862. Vavasseur, Josiah, 28 Gravel Lane, Southwark, London, S.E.; and Rothbury, Blackheath Park, London, S.E. [*Exemplar, London.*]

1889. Vesian, John Stuart Ellis de, 20 New Bridge Street, Blackfriars, London, E.C. [*Biceps, London.*]

1891. Vicars, John, Gillbank, Boot, viâ Carnforth.

1865. Vickers, Albert, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1861. Vickers, Thomas Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1888. Voysey, Henry Wesley, 1 Fordwych Road, Brondesbury, London, N.W.

1856. Waddington, John, 35 King William Street, London Bridge, London, E.C.

1879. Wadia, The Hon. Nowrosjee Nesserwanjee, C.I.E., Messrs. Nowrosjee Wadia and Sons, Tardeo, Bombay: Bella Vista, Cumballa Hill, Bombay: (or care of Messrs. Hick Hargreaves and Co., Soho Iron Works, Bolton.) [*Wadia, Bombay.*]

1882. Wailes, George Herbert, St. Andrews, Watford, Herts.

1884. Wailes, Thomas Waters, General Manager, Mountstuart Dry Dock and Engineering Works, Cardiff. [*Mountstuart, Cardiff.*]

1888. Waister, William Henry, Assistant Locomotive Superintendent, Great Western Railway, Stafford Road Works, Wolverhampton.

1881. Wake, Henry Hay, Engineer to the River Wear Commission, Sunderland.

1882. Wakefield, William, 123 Rathgar Road, Dublin.

1892. Waldron, Patrick Lawrence, R.N.R., Rockville Cottage, Castletown Berehaven, Co. Cork, Ireland; and 24 St. Joseph's Road, Aughrim Street, Dublin.

1891. Walker, Arthur Tannett, Messrs. Tannett Walker and Co., Goodman Street Works, Hunslet, Leeds.

1875. Walker, George, 95 Leadenhall Street, London, E.C.

1890. Walker, Henry, 11 Oxford Terrace, Gateshead.

1894. Walker, Henry Claude, Messrs. R. Waygood and Co., Falmouth Road, Great Dover Street, London, S.E. [*Waygood, London.* 4760.]

1875. Walker, John Scarisbrick, Messrs. J. S. Walker and Brother, Pagefield Iron Works, Wigan; and 41 Leyland Road, Southport. [*Pagefield, Wigan.*]

1884. Walker, Sydney Ferris, Cardiff Electrical Works, Severn Road, Cardiff [*Dynamo, Cardiff.*]; and Hunter's Forge, New Bridge Street, Newcastle-on-Tyne. [*Dynamo, Newcastle-on-Tyne.*]

1876. Walker, Thomas Ferdinand, Ship's Log Manufacturer, 58 Oxford Street, Birmingham.

1890. Walker, William George, 47 Victoria Street, Westminster, S.W.

1878. Walker, Zaccheus, Jun., Fox Hollies Hall, near Birmingham.

1884. Wallace, John, Backworth Collieries, near Newcastle-on-Tyne.

1895. Wallace, Joseph, Tennant's Agency, San Fernando, Trinidad.

1884. Wallau, Frederick Peter, Superintendent Engineer, Union Steam Ship Co., Southampton.

1868. Wallis, Herbert, 239 Drummond Street, Montreal, Canada.

1893. Wallwork, Roughsedge, Union Bridge Iron Works, Charter Street, Manchester.

1891. Walmsley, John, Messrs. J. and P. Coats, Ferguslie Thread Works, Paisley.

1865. Walpole, Thomas, Messrs. Ross and Walpole, North Wall Iron Works, Dublin. [*Iron, Dublin.* 311.]

1877. Walton, James, 28 Maryon Road, Charlton, Kent.

1881. Warburton, John Seaton, 19 Stanwick Road, West Kensington, London, W.

1882. Ward, Thomas Henry, 22 Ampthill Road, Bedford.

1876. Ward, William Meese, Newton Villa, Claremont Road, Handsworth, R.O., near Birmingham.

1864. Warden, Walter Evers, Phœnix Bolt and Nut Works, Handsworth, R.O., near Birmingham. [*Bolts, Birmingham.*]

1882. Wardle, Edwin, Messrs. Manning Wardle and Co., Boyne Engine Works, Hunslet, Leeds. [*Manning, Leeds.*]

1886. Warren, Frank Llewellyn, 73 Breakspears Road, St. John's, London, S.E.

1885. Warren, Henry John, Jun., Cornwall Boiler Works, Camborne.

1885. Warren, William, Chief Engineer, Midland Uruguay Railway, Paysandu, Uruguay: (or care of Walter Ross, Hill Top, Blythe Hill, Catford, London, S.E.)

1889. Warsop, Thomas, Coniston Copper Mines, Coniston, S.O., Lancashire.

1858. Waterhouse, Thomas (*Life Member*), Claremont Place, Sheffield.

1891. Waterous, Julius E., Waterous Wire Nail Works, Brantford, Ontario, Canada.

1881. Watkins, Alfred, 58 Fenchurch Street, London, E.C.

1862. Watkins, Richard, 18 Cambridge Gardens, Hastings.

1890. Watkinson, William Henry, Professor of Motive Power Engineering, Glasgow and West of Scotland Technical College, 38 Bath Street, Glasgow.

1890. Watson, George Coghlan, Manganese Bronze and Brass Co., St. George's Wharf, Deptford, London, S.E.; and Granville House, Bedford Park, Croydon.

1882. Watson, Henry Burnett, Messrs. Henry Watson and Son, High Bridge Works, Newcastle-on-Tyne. [*Watsons, Newcastle-on-Tyne.* 439.]

1896. Watson, James Falshaw, 15 Shaw Lane, Headingley, Leeds. [*Inspection, Leeds.*]

1879. Watson, Sir William Renny, 16 Woodlands Terrace, Glasgow.

1877. Watts, John, Broad Weir Engine Works, Bristol.

1886. Weatherburn, Robert, Locomotive Manager, Midland Railway Works, Kentish Town, London, N.W.

1894. Webb, Henry, Messrs. Joseph Webb and Co., Irwell Forge and Rolling Mills, Bury, Lancashire.

1884. Webb, Richard George, Messrs. Richardson and Cruddas, Byculla Iron Works, Bombay, India: (or care of Messrs. Richardson and Hewett, 101 Leadenhall Street, London, E.C.)

1890. Webster, John James, 39 Victoria Street, Westminster, S.W.

1887. Webster, William, 6 Oxley Road, Singapore, Straits Settlements.

1883. Weck, Friedrich, Lilleshall Old Hall, near Newport, Shropshire.

1891. Weightman, Walter James, Engineer-in-Chief, Nilgiri Railway, Coonoor, Madras, India.

1888. Wellman, Samuel T., Wellman Seaver Engineering Co., New England Building, Cleveland, Ohio, United States.

1882. West, Charles Dickinson, Professor of Mechanical Engineering, Imperial College of Engineering, Tokyo, Japan.

1876. West, Henry Hartley, Naval Architect and Engineer, 5 Castle Street, Liverpool. [*Referee, Liverpool.* 5223.]

1894. West, James, Post Office, Koffyfontein Mines, Orange Free State, South Africa.

1894. West, John, Albion Iron Works, Miles Platting, Manchester.

1891. West, Leonard, Ravenhead Plate Glass Works, St. Helen's, Lancashire.

1874. West, Nicholas James, Trevales Mansion, St. Stythians, Perranarworthal, Cornwall.

1877. Western, Charles Robert, Broadway Chambers, Westminster, S.W. [*Donbowes, London.* 3199.]

1877. Western, Maximilian Richard, care of Colonel Western, C.M.G., Broadway Chambers, Westminster, S.W.

1895. Westmacott, Henry Armstrong, Messrs. John Spencer and Sons, Newburn Steel Works, Newcastle-on-Tyne.

1862. Westmacott, Percy Graham Buchanan, Sir W. G. Armstrong Mitchell and Co., Elswick Engine Works, Newcastle-on-Tyne; and Benwell Hill, Newcastle-on-Tyne.

1880. Westmoreland, John William Hudson, Lecturer on Engineering, University College, Nottingham.

1880. Westwood, Joseph, Barkway, Herts.

1888. Weyman, James Edwardes, Messrs. Markham and Co., Broad Oaks Iron Works, Chesterfield.

1896. Wheeler, Percy, General Manager, Oldbury Railway-Carriage and Wagon Works, Oldbury, near Birmingham. [*Carriage Co., Oldbury.*]

1894. Whitby, Arthur George, The Limes, Amersham.

1882. White, Alfred Edward, Borough Engineer's Office, Town Hall, Hull.

1887. White, Alfred George, 11 Queen Victoria Street, London, E.C.

1888. White, Sir William Henry, K.C.B., LL.D., F.R.S., Assistant Controller and Director of Naval Construction, Admiralty, Whitehall, London, S.W.

1890. Whitehouse, Edwin Edward Joseph, Monkbridge Iron Works, Leeds.

1876. Whiteley, William, Holly Mount, Edgerton, Huddersfield.

1891. Whittaker, John, Messrs. William Whittaker and Sons, Sun Iron Works, Oldham.

1869. Whittem, Thomas Sibley, Wyken Colliery, Coventry.

1878. Whytehead, Hugh Edward, Meadowside, Mayfield Road, Moseley, Birmingham.

1878. Wicks, Henry, Messrs. Burn and Co., Howrah Iron Works, Howrah, Bengal, India: (or care of John Spencer, 125 West Regent Street, Glasgow.)

1868. Wicksteed, Joseph Hartley, Messrs. Joshua Buckton and Co., Well House Foundry, Meadow Road, Leeds.

1891. Widdowson, John Henry, Britannia Works, Ordsal Lane, Salford, Manchester.

1878. Widmark, Harald Wilhelm, Helsingborgs Mekaniska Verkstad, Helsingborg, Sweden.

1889. Wigham, John Richardson, Messrs. Edmundsons, Stafford Works, 35 Capel Street, Dublin.

1881. Wigzell, Eustace Ernest, Billiter House, Billiter Street, London, E.C. [*Wigzell, London.* 1844.]

1886. Wildridge, John, Messrs. J. Wildridge and Sinclair, 97 Pitt Street, Sydney, New South Wales: (or care of R. Wildridge, 7 Alexandra Crescent, Newcastle-on-Tyne.)

1890. Wildy, William Lawrence, 32 Petherton Road, Highbury New Park, London, N.

1892. Wilkinson, Edward R., Ellerton Lodge, Church End, Finchley, London, N.

1885. Willcox, Francis William, 45 West Sunniside, Sunderland.

1893. Williams, Arthur Edward, Resident Engineer, Dagenham Dock, Essex.

1883. Williams, Sir Edward Leader, Engineer, Manchester Ship Canal Co., 41 Spring Gardens, Manchester [*Leader, Manchester.* 688.]; and The Oaks, Altrincham.

1884. Williams, John Begby, Central Marine Engine Works, West Hartlepool.

1885. Williams, Nicholas Thomas, General Manager, Witwatersrand Gold Mine, P.O. Box 1019, Johannesburg, Transvaal, South Africa.

1847. Williams, Richard (*Life Member*), Brunswick House, Wednesbury.

1890. Williams, Thomas David, 16 Lancaster Road, South Norwood, London, S.E.

1881. Williams, William Freke Maxwell, 29 Great St. Helen's, London, E.C. [*Wabash, London.*]

1873. Williams, William Lawrence, 16 Victoria Street, Westminster, S.W. [*Snowdon, London.*]

1889. Williams, William Walton, Jun., 87 Elspeth Road, New Wandsworth, London, S.W.

1896. Williamson, Joseph, São Paulo Railway, São Paulo, Brazil.

1883. Williamson, Richard, Messrs. Richard Williamson and Son, Iron Shipbuilding Yard, Workington; and South Lodge, Cockermouth.

1878. Wilson, Alexander, Messrs. Charles Cammell and Co., Cyclops Steel and Iron Works, Sheffield.

1882. Wilson, Alexander Basil, Holywood, Belfast. [*Wilson, Holywood.* 201.]

1884. Wilson, James, Pacha, Chief Engineer of the Daira Sanieh, Egypt: Cairo, Egypt.

1881. Wilson, John, Engineer, Great Eastern Railway, Liverpool Street Station, London, E.C. [*Wilson, Eastern, London.*]

1863. Wilson, John Charles, 39 Victoria Street, Westminster, S.W.

1892. Wilson, John Charles Grant, Locomotive Superintendent, Manila Railway, Manila, Philippine Islands.

1879. Wilson, Joseph William, Principal of School of Practical Engineering, Crystal Palace, Sydenham, London, S.E.

1890. Wilson, Joseph William, Jun., Vice-Principal of School of Practical Engineering, Crystal Palace, Sydenham, London, S.E.

1880. Wilson, Robert, 10 St. Bride Street, London, E.C.; and 7 St. Andrew's Place, Regent's Park, London, N.W.

1883. Wilson, Robert, F.R.S.E., 13 Victoria Street, Westminster, S.W.

1890. Wilson, Robert James, care of Thomas Wilson, The Firs, Muswell Hill, London, N.

1891. Wilson, Thomas, Morro Foundry, Iquique, Chile.

1873. Wilson, Thomas Sipling, Messrs. Holroyd Horsfield and Wilson, Larchfield Foundry, Hunslet Road, Leeds.

1888. Wilson, Walter Henry, Messrs. Harland and Wolff, Belfast.

1881. Wilson, Wesley William, Messrs. A. Guinness Son and Co., St. James' Gate Brewery, Dublin.

1891. Wimshurst, James Edgar, Messrs. William Esplen, Son, and Swainston, Billiter Buildings, 22 Billiter Street, London, E.C.

1890. Winder, Charles Aston, Messrs. Winder Brothers, Royds Works, Attercliffe, Sheffield.

1886. Windsor, Edwin Wells, 1 Rue du Hameau des Brouettes, Rouen, France.

1890. Wingfield, Digby Charles, 61 Parliament Hill Road, Hampstead, London, N.W.

1887. Winmill, George, Locomotive and Carriage Superintendent, Oudh and Rohilkund Railway, Lucknow, India: (or Harewood, Junction Road, Romford.)

1872. Wise, William Lloyd, 46 Lincoln's Inn Fields, London, W.C. [*Lloyd Wise, London.* 65378.]

1884. Withy, Henry, Messrs. Furness Withy and Co., Middleton Ship Yard, West Hartlepool. [*Withy, West Hartlepool.* 4.]

1878. Wolfe, John Edward, Sunderland and South Shields Water Co., 16 Fawcett Street, Sunderland.

1878. Wolfenden, Robert, Revenue Cutter "Ling Fêng," care of Commissioner of Customs, Shanghai, China: (or 25 Grafton Street, Moss Side, Manchester.)

1888. Wolff, Gustav William, M.P., Messrs. Harland and Wolff, Belfast.

1881. Wood, Edward Malcolm, 3 Victoria Street, Westminster, S.W.

1887. Wood, Henry, Messrs. John and Edward Wood, Victoria Foundry, Bolton.

1880. Wood, John Mackworth, Engineer's Department, New River Water Works, Clerkenwell, London, E.C.

1868. Wood, Lindsay, Mining Engineer, Southhill, near Chester-le-Street.

1884. Wood, Sidney Prescott, Semaphore Iron Works, Newport, Melbourne, Victoria: (or care of H. W. Little, Messrs. McKenzie and Holland, Vulcan Iron Works, Worcester.)

1890. Wood, Thomas Royle, care of Samuel Bash, 1663 Avenida Montes de Oca, Buenos Aires, Argentine Republic: (or care of William Wood, 28 Hyde Grove, Chorlton-on-Medlock, Manchester.)

1896. Wood, Walter Chapman, care of Messrs. J. Buchheister and Co., Shanghai, China.

1890. Wood, William, 37 Wolfington Road, West Norwood, London, S.E.

1882. Woodall, Corbet, Palace Chambers, 9 Bridge Street, Westminster, S.W.

1894. Woods, William Henry, Messrs. Hamilton Woods and Co., Liver Foundry and Engine Works, Ordsal Lane, Salford, Manchester. [*Sluice, Manchester.* 1962.]

1895. Wordingham, Charles Henry, Electric Light Station, Dickinson Street, Manchester.

1887. Worger, Douglas Fitzgerald, Assistant Engineer, Southwark and Vauxhall Water Works, Southwark Bridge Road, London, S.E.

1893. Wormald, Henry, Resident Engineer, Ackton Hall Colliery, Featherstone, near Pontefract.

1874. Worsdell, Thomas William, Stonycroft, Arnside, near Carnforth.

1894. Worsdell, Wilson, Locomotive Superintendent, North Eastern Railway, Gateshead.

1877. Worssam, Henry John, Messrs. G. J. Worssam and Son, Wenlock Road, City Road, London, N. [*Massrow, London.* 6656.]

1886. Worthington, Charles Campbell, Messrs. Henry R. Worthington, Hydraulic Works, 145 Broadway, New York, United States: (or care of the Worthington Pumping Engine Co., 153 Queen Victoria Street, London, E.C.)

1888. Worthington, Edgar, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester; and Mill Bank, Bowdon, near Altrincham.

1860. Worthington, Samuel Barton, Consulting Engineer, 33 Princess Street, Manchester; and Mill Bank, Bowdon, near Altrincham.

1881. Wrench, John Mervyn, Chief Engineer, Indian Midland Railway, Jhansi, N.W. Provinces, India.

1876. Wright, James, Messrs. Ashmore Benson Pease and Co., Stockton-on-Tees. [*Wright, Gasholder, Stockton.* 12.]

1867. Wright, John Roper, Messrs. Wright Butler and Co., Elba Steel Works, Gower Road, near Swansea.

1859. Wright, Joseph, Metropolitan Railway-Carriage and Wagon Co., Saltley Works, Birmingham; and The Gresham Club, London, E.C.

1895. Wright, William, 16 Great George Street, Westminster, S.W.; and Dudley, 8 Louvaine Road, New Wandsworth, London, S.W.

1871. Wrightson, Thomas, Messrs. Head Wrightson and Co., Teesdale Iron Works, Stockton-on-Tees.

1891. Wroe, Joseph, 26 Park Avenue, Manchester, S.E.

1891. Wylde, Thomas, P. O. Box 1048, Johannesburg, Transvaal, South Africa; and care of Messrs. F. A. Robinson and Co., 54 Old Broad Street, London, E.C.

1886. Wylie, James, 218 Alfreton Road, Nottingham.

1895. Wylie, John Condie, Appantoo Gold Mining Co., Axim, Gold Coast Colony: (or Pendarves Road, Camborne.)

1865. Wyllie, Andrew, 1 Leicester Street, Southport.

1877. Wyvill, Frederic Christopher, 19 East Parade, Leeds.

1889. Yarrow, Alfred Fernandez, Isle of Dogs, Poplar, London, E.

1895. Yarwood, William James, Works Manager, River Weaver Navigation, Northwich.

1881. Yates, Louis Edmund Hasselts, District Locomotive and Carriage Superintendent, Eastern Bengal State Railway, Saidpore, Bengal, India: (or care of Rev. H. W. Yates, 98 Lansdowne Place, Brighton.)

1880. York, Francis Colin, Locomotive Superintendent, Buenos Aires and Pacific Railway, Junin, Buenos Aires, Argentine Republic: (or care of W. Hannay, 18 Portland Street, Leamington.)

1889. Young, David, 11 and 12 Southampton Buildings, London, W.C. [*Junkring, London.*]

1879. Young, George Scholey, Engineer, Thames Iron Works, Orchard Yard, Blackwall, London, E.

1874. Young, James, 19 Wentworth Place, Newcastle-on-Tyne.

1892. Young, Robert, Engineer and Manager, Penang Steam Tramways, Penang, Straits Settlements.

1894. Young, Smelter Joseph, Messrs. Spear and Jackson, Ætna Works, Savile Street East, Sheffield.

1887. Young, William Andrew, Messrs. Lobnitz and Co., Renfrew, near Paisley [*Lobnitz, Renfrew.* 57, *Paisley.*]; and Millburn House, Renfrew, near Paisley.

1881. Younger, Robert, Messrs. R. and W. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.

ASSOCIATE MEMBERS.

1896. Abady, Jacques, Messrs. Alexander Wright and Co., 19 and 21 Old Queen Street, Westminster, S.W.

1896. Abella, Juan, Director General of Public Lighting, 691 Calle Bolivar, Buenos Aires, Argentine Republic.

1896. Adams, George, 55 Victoria Street, Westminster, S.W.

1895. Ahrons, Ernest Leopold, Managing Engineer of Technical School, Ecole Khédiviale d'Arts et Métiers, Cairo, Egypt.

1890. Alderson, George Alexander, Norland House, Ramleh, Alexandria, Egypt.

1894. Almond, Michael, District Locomotive Inspector, Cape Government Railways, Queenstown, South Africa: (or care of Robert Almond, 21 Hawthorn Road, South Gosforth, Newcastle-on-Tyne.)

1894. Ambler, Frank, Assistant Resident Engineer, Alagoas Railway, Maceio, Brazil.

1895. Armstrong, George Edwin, Municipal Technical School, York Place, Brighton.

1889. Ashford, John, Engineering Department, Northampton Institute, Clerkenwell, London, E.C.

1896. Atkinson, Frederic, Albert Buildings, 49 Queen Victoria Street, London, E.C. [*Fixed, London.*]

1894. Aveline, William Rebotier, Messrs. George Gahagan and Co., Bellasis Road, Byculla, Bombay, India.

1896. Barba, Alfonso G., Messrs. J. and G. Thomson, Clydebank, Glasgow; and 3 Craignethan Gardens, Partick, Glasgow.

1896. Barker, Arthur Henry, 62 Alderney Street, Eccleston Square, London, S.W.

1893. Barker, Frederic William, 33A Hammersmith Broadway, London, W. [*Barker, Broadway, Hammersmith.*]; and 28 Prebend Gardens, Chiswick, London, W.

1895. Barnes, James, 75 Dickenson Road, Rusholme, Manchester.

1894. Baron, Francis Edward, Great Horseless Carriage Co., Motor Mills, Coventry.

1896. Baron, James Thomas, Resident Engineer, St. Pancras Electricity and Public Lighting Department, 47 Stanhope Street, London, N.W.

1896. Barton, Andrew, care of W. Duff Bruce, 17 Victoria Street, Westminster, S.W.

1893. Beazley, Ernest, care of Messrs. Antonio Giorgi and Co., Funchal, Madeira.

1895. Bennis, Alfred William, Messrs. E. Bennis and Co., Lancashire Stoker Works, Deansgate Foundry, Bolton.
1893. Bishop, Henry, 38 Gresham Street, Lincoln.
1895. Blaxter, Augustus Pearce, Jun., Messrs. Barnett and Foster, Niagara Works, Eagle Wharf Road, New North Road, London, N.
1896. Blumfield, Thomas William, 11 Wren Street, Coventry.
1896. Bosley, Walter Joseph, Resident Engineer, Guildford Main Drainage Outfall Works, Stoke-by-Guildford.
1895. Boulden, Frederick, The Technical School, St. George's Square, Sheffield.
1896. Bremner-Davis, William Joseph, 6 Heald Place, Moss Lane East, Manchester.
1892. Bromly, Alfred Hammond, care of Thomas Hammond, Stanwell Street, Colchester.
1895. Bruce, Robert Arthur, Brennan Torpedo Factory, Chatham.
1893. Burden, Alfred George, Messrs. Tangyes, P. O. Box 818, Johannesburg, Transvaal, South Africa: (or care of George N. Burden, Oakfield, Teignmouth.)
1895. Burn, George Francis, The Technical School, Cookridge Street, Leeds.
1890. Burne, Edward Lancaster, Messrs. Dickinson and Burne, Church Acre Iron Works, Guildford.
1896. Butcher, Malcolm Henry, Messrs. F. A. Robinson and Co., 54 Old Broad Street, London, E.C.
1891. Buttenshaw, George Eskholme, Messrs. Guest and Chrimes, Brass Works, Rotherham.

1896. Carolin, Edward Marlay, P. O. Box 80, Bloemfontein, Orange Free State, South Africa.
1895. Carver, Charles Frederick, Alfred Street Machine Works, Nottingham. [*Carver, Nottingham.*]
1895. Challenger, Godfrey Richard, Messrs. John Jameson and Son, Bow Street Distillery, Dublin.
1896. Clare, Ernest, care of Sidney Straker, 139 Cannon Street, London, E.C.
1894. Clark, James Lester, Messrs. Clark and Aiton, 102 Fenchurch Street, London, E.C. [*Channeled, London.*]
1895. Clatworthy, Walter Angove, 29 Lily Avenue, Jesmond, Newcastle-on-Tyne.
1894. Collis, Alfred Edward, Lincoln Science School, Monk's Road, Lincoln.
1896. Comerford, Edward, Laragh, Victoria Park, Wavertree, Liverpool.
1896. Conradi, Julius Samuel, Messrs. John I. Thornycroft and Co., Church Wharf, Chiswick, London, W.

1896. Cooper, Thomas, Cox Thermo Electric Co., St. Albans; and Spring Valley, Beaconsfield Road, St. Albans.

1895. Corby, Matthew, Messrs. Thomas Firth and Sons, Norfolk Works, Sheffield; and 160 Hagley Road, Birmingham.

1893. Corkhill, William, Manager, Shalimar Engineering and Shipbuilding Works, Calcutta, India.

1894. Coventry, Theodore, Messrs. Smith and Coventry, Gresley Iron Works, Ordsal Lane, Salford, Manchester. [*Gresley, Manchester.* 564.]

1893. Cowell, John Ray, P.O. Box 2141, Johannesburg, Transvaal, South Africa.

1895. Cowie, William, Lidgerwood Manufacturing Co., Soerabaya, Java.

1896. Cox, Edward Henry, De la Vergne Refrigerating Machine Co., Foot of East 138th Street, New York, United States.

1887. Crosland, Delevante William, 22 Royal Crescent, Kensington, London, W.

1895. Cust, Leopold, Gas Traction Co., 22 Chancery Lane, London, E.C.; and 99 Onslow Square, London, S.W.

1894. Dadina, Hormuz Minocher, Consulting Engineer, Khetwady, Bombay, India.

1894. Davey, Edward Ernest George, 15 Westmoreland Street, Marylebone, London, W.

1896. Davidson, John McKenzie, Messrs. McKenzie and Co., Karachi, India.

1896. Davis, Francis Myddleton, Works Manager, Messrs. R. and T. Elworthy, Elizabethgrad, Russia.

1896. Dawson, Philip, 39 Victoria Street, Westminster, S.W.

1890. Day, Arthur Godfrey, Director of Studies, Science Art and Technical Schools, Guildhall, Bath.

1894. Dickinson, Harold, Central Electric Lighting Station, Yorkshire House to House Electricity Co., Whitehall Road, Leeds. [*Electricity, Leeds.* 1013.]

1896. Dossor, Herbert, Babcock and Wilcox Co., 147 Queen Victoria Street, London, E.C.

1891. Douglass, Alfred Edwards, South Staffordshire Water Works, Paradise Street, Birmingham.

1896. Dowson, Erasmus Charles Head, Northey Manufacturing Co., Toronto, Ontario, Canada.

1895. Dronsfield, James, Messrs. Dronsfield Brothers, Atlas Works, Oldham.

1895. Dubrule, Louis Henri Jean Baptiste, Messrs. Dujardin and Co., Lille, France.

1895. Dumas, Robert, Messrs. Siemens Brothers and Co., Woolwich.

1895. Duncan, William, Locomotive Department, Cape Government Railways, Uitenhage, Cape Colony.

1895. Dunn, Matthew, Manager, Gas Works, Selby.
1894. Dunolly, Alan, Farley, Reigate.

1894. Eastmead, Frederic James, Messrs. Moffatt and Eastmead, 39 Victoria Street, Westminster, S.W. [*Hoistway, London.*]
1892. Edgcome, James Edmund, Resident Engineer, Electric Light Station, Kingston-on-Thames.
1893. Edmondson, Alfred Richard, Central Board School, Deansgate, Manchester.
1891. Edwards, Herbert Francis, Messrs. Forster Brown and Rees, Guildhall Chambers, Cardiff.

1895. Fawcett, Percy William, Whirlow Court, Sheffield.
1894. Fendick, Walter, Gas Works, Hemel Hempstead.
1896. Fforde, William John, 2 Glenview Terrace, Springfield Road, Belfast.
1894. Finlayson, David, Burnhead, Larbert, Stirlingshire.
1896. Firth, John, Municipal Technical Schools, Hull; and 7 All Saints' Street, Hull.
1894. Fitz-Gerald, John Frederick Gerald, care of El Señor Ingeniero, Departamento de Vias y Obras F.C.S., Buenos Aires, Argentine Republic.
1895. Fleischer, Paul, Messrs. A. Guinness, Son and Co., St. James' Gate Brewery, Dublin.
1892. Fletcher, Joseph Ernst, Messrs. Charles Cammell and Co., Cyclops Works, Sheffield.
1895. Forbes, George Chichester, 4 Chester Crescent, Newcastle-on-Tyne.
1895. Foster, Edward Hornby, Messrs. John Foster and Son, Black Dike Spinning Mills, Queensbury, near Bradford.
1896. Fowler, Henry, Lancashire and Yorkshire Railway, Horwich, near Bolton.
1896. Fraser, Frank Hazell, Messrs. W. J. Fraser and Co., 98 Commercial Road East, London, E. [*Fraser, Engineer, London.* 4413.]

1896. Gallé, William Alexandre, Locomotive Works, Manchester Sheffield and Lincolnshire Railway, Gorton, Manchester.
1896. Garratt, Herbert Alfred, Northern Polytechnic Institute, Holloway Road, London, N.
1896. Garratt, James Herbert, Messrs. Whittall and Co., Colombo, Ceylon.
1896. Garrett, Easton, 186 San Martin, Buenos Aires, Argentine Republic.
1896. Given, Ernest Cranston, Messrs. Priestman and Co., Philadelphia, Pennsylvania, United States; and The Lodge, Aigburth, Liverpool.
1896. Goffe, Edward, De Beer's Consolidated Mines, Kimberley, South Africa.
1893. Grant, William, care of A. Basil Wilson, Martello Terrace, Holywood, Belfast.

1896. Gray, Alexander Cuthill, Messrs. Campbell and Hall, 94 Broomielaw, Glasgow.

1895. Greene, William Spencer Clayton, 33 Norfolk Street, Strand, London, W.C.; and 47 Edwardes Square, London, W. [*Shipworm, London.*]

1893. Gritton, Joseph, P. O. Box 1798, Johannesburg, Transvaal, South Africa: (or 97 Highbury Quadrant, London, N.)

1895. Groundwater, Samuel, Messrs. S. C. Farnham and Co., Old Dock, Shanghai, China.

1895. Groves, Montague, Moore's Rhodesia Concession, Salisbury, Mashonaland, South Africa.

1894. Hadengue, Charles Benjamin, Messrs. Carew and Co., Rosa Sugar Works, Rosa, North Western Provinces, India.

1895. Haines, Charles James, Southampton Water Works, Otterbourne, near Winchester.

1896. Hall, Benjamin James, 39 Victoria Street, Westminster, S.W.

1894. Hall, Robert Frederick, Ferndale, Church Road, Moseley, Birmingham.

1894. Hardy, William, Woodview, Bessbrook, County Armagh, Ireland.

1894. Harris, Herbert Nelson, St. Michael's Foundry, Bridport.

1896. Hawes, David Marc Andrew Graham, Messrs. Joseph J. Byers and Co., 40 King Street, Cheapside, London, E.C.

1896. Heath, Charles Lewis Eclair, Municipal Technical School, 86 Osborne Street, Hull.

1894. Henderson, Arthur James, 2 Lombard Court, Gracechurch Street, London, E.C.

1896. Hill, Thomas, Spoutmouth, Gallowgate, Glasgow. [*Specify, Glasgow.* 4758.]

1895. Hockley, Norman Julius, Engineer, Corporation Electricity Works, Burton-on-Trent.

1896. Hollingsworth, Edward Massey, Corporation Gas Works, Warrington Old Road, St. Helen's, Lancashire.

1895. Horner, Joseph Gregory, 17 Vernon Terrace, Twerton-on-Avon, Bath.

1895. House, Henry A., Jun., Manager, Liquid Fuel Engineering Co., Columbine Ship Yard, East Cowes, Isle of Wight.

1894. Hyde, George Herbert, Managing Engineer, Colombo Commercial Co., Colombo, Ceylon.

1896. Iden, George, London Brighton and South Coast Railway Works, Brighton.

1895. Ingham, William, Water Engineer, Torquay.

1896. Issigonis, George Demos, The D. Issigonis Works, Smyrna, Turkey in Asia.

1893. Jenkin, Charles James, Council Offices, Willenhall, Wolverhampton.
1896. Johnson, Andrew, 120 Nithsdale Road, Glasgow.
1896. Jones, Thomas Gilbert, The Technical School, Mount Pleasant, Swansea.

1895. Kennedy, Robert Baird, Fish Dock Road, Grimsby.
1896. Kerr, Alfred Ernest Campbell (*Life Associate Member*), The School of Mines, Ballarat, Victoria.
1893. Kershaw, Thomas, Technical School, Huddersfield.
1894. Kerslake, Walter Edmund, 34 Great George Street, Liverpool.
1893. Kirk, Percy Roebuck, Seafield Park, Crofton, Hants.

1895. Larard, Charles Edward, Battersea Polytechnic Institute, Battersea, London, S.W.
1896. Lawson, Harry John, 40 Holborn Viaduct, London, E.C.
1893. Lea, Arthur Henry, Messrs. Lea and Warren, Kettering.
1895. Longbottom, John Gordon, 11 Grassington Terrace, Keighley.
1896. Lovell, Samuel George, care of W. G. Walker, 47 Victoria Street, Westminster, S.W.

1896. Malloch, William Farquhar, P.O. Box 2303, Johannesburg, Transvaal, South Africa.
1896. Mansfield, Alfred, Manager, Messrs. P. Orr and Sons, Mount Road, Madras, India.
1894. Mansfield, Edwin Albert, 1 Aldermanbury Buildings, London, E.C.
1893. Manton, Arthur Woodroffe, Central London Railway, 7 Holland Park Avenue, London, W.
1896. Martin, George Best, Works Manager, British Tube Co., Cornwall Road, Smethwick, Birmingham.
1895. Massey, Leonard Fletcher, Messrs. B. and S. Massey, Openshaw, Manchester. [*Masseys, Openshaw.* 300.]
1896. McCormack, William John, 29 Bow Lane, Cannon Street, London, E.C.
1894. McGeorge, James, Bombay Burmah Trading Corporation, Rangoon, British Burmah, India.
1891. McMeekin, Adam, Cogry Flax Spinning Mills, Doagh R.S.O., Co. Antrim, Ireland.
1895. Messer, Edgar Harrisson, P.O. Box 1940, Johannesburg, Transvaal, South Africa: (or care of John Messer, Danbury, Alexandra Road, Reading.)
1894. Mills, Arthur Edwin, 4 Victoria Terrace, Clifton, Bristol.
1893. Mitchell, James Frederick Bruce, Messrs. J. F. B. Mitchell and Co., Mazagon Iron Works, Bombay, India.
1896. Mitton, Thomas Evans, Messrs. Hunt and Mitton, Crown Brass Works, Oozells Street North, Birmingham. [*Mitton, Birmingham.* 394.]

1894. Monckton, Charles John, Superintendent Engineer, Messrs. T. H. Saunders and Co., Darenth Paper Mill, near Dartford.

1896. Moncrieff, Robert Wighton, Brafield, Northampton.

1895. Moore, Thomas Lamb, Messrs. James Moore and Sons, Millfield Foundry, Belfast. [*Moore, Millfield, Belfast.* 466.]

1893. Mountain, Benjamin, Blenheim Square, Leeds.

1895. Mount-Haes, Andrew, 84 Tierney Road, Streatham Hill, London, S.W.

1893. Moylan, William Morgan, care of Messrs. Grindlay and Co., Calcutta, India.

1894. Murphy, Edward Owen, R.N.R., Chief Engineer, R.M.S. "Empress of Japan," Vancouver, British Columbia.

1889. Nasmith, Joseph, 61 Barton Arcade, Manchester.

1895. Nesbit, David Mein, Messrs. Ashwell and Nesbit, 12 Great James Street, Bedford Row, London, W.C. [*Platerack, London.*]; and Victoria Foundry, Leicester.

1896. New, Alfred Wilmot, Renwick Chambers, Sylvester Street, Coolgardie, Western Australia.

1896. New, David James, care of Messrs. D. New and Co., 28 Devonshire Chambers, Bishopsgate Street Without, London, E.C.

1896. Newell, Ernest, Messrs. Edward Ripley and Sons, Bowling Dye Works, Bradford.

1896. Nicholls, Percy, General Electric Co., Peel Works, Salford, Manchester.

1894. North, Horace, St. George's Engineering Works, Trafalgar Street, Brighton.

1896. Parker, John, Messrs. E. Green and Son, 2 Exchange Street, Manchester.

1896. Patel, Motibhai Bhikhabhai, Bhadran, near Borsad, India.

1896. Patel, Raojibhai Motibhai, Principal, Kala-Bhavan, Baroda, India.

1893. Paterson, Robert Mair, 78 Broadhurst Gardens, Hampstead, London, N.W.

1896. Pendred, Loughnan St. Lawrence, 33 Norfolk Street, Strand, London, W.C.

1895. Penn, William Cooper, 15 Victoria Street, Westminster, S.W. [*Penniform, London.* 3075.]

1893. Pertwee, Herbert Arthur, Messrs. Elliott's Metal Co., Pembrey Copper Works, Burry Port, R.S.O., Carmarthenshire.

1895. Phillips, Exham, Crescent Iron Works, Salford, Manchester; and Rostellan, Worsley, Manchester.

1891. Pirrie, John Barbour, Barn Flax Spinning Mills, Carrickfergus, Co. Antrim, Ireland.

1896. Pollard, Ferdinand Joseph, P.O. Box 2485, Johannesburg, Transvaal, South Africa.

1894. Poppleton, Clement Francis, 8 Clifden Road, Clapton, London, N.E.
1895. Powell, Benjamin Newton, Manager, Lidgerwood Manufacturing Co., Soerabaya, Java: (or care of C. T. Powell, Cherry Street, Birmingham.)
1887. Price-Williams, John Morgan, 28 Ormiston Road, Westcombe Park, Blackheath, London, S.E.
1896. Pritchard, Hugh, Dinorwic Slate Quarries, Llanberis, near Carnarvon; and 14 Terfyn Terrace, Port Dinorwic, near Bangor.
1895. Pugh, Charles Vernon, 34 Spon Street, Coventry.
1895. Pullar, Albert Evans, Pullar's Dye Works, Perth.

1894. Raleigh, Charles, 32 Randolph Gardens, Maida Vale, London, W.
1896. Rayner, Harry Stafford, Dowson Economic Gas and Power Co., 39 Old Queen Street, Westminster, S.W.; and 68 Norroy Road, Putney, London, S.W.
1893. Richey, William Frederick Albert, Messrs. Chance Brothers and Co., Lighthouse Works, near Birmingham.
1895. Ridley, Clarence Oliver, Sir W. G. Armstrong, Mitchell and Co., 8 Great George Street, Westminster, S.W.
1896. Rieter, E. Henry, Messrs. J. J. Rieter and Co., Winterthur, Switzerland.
1893. Roberts, Charles Thomas, 19 and 23 Chorlton Chambers, Johannesburg, Transvaal, South Africa. [*Roberts, Engineer, Johannesburg.*]
1895. Ross, Ernest Sydney, Inspection of Machinery Department, Macquarie Street, Hobart, Tasmania.
1894. Rossiter, James Thomas, Tynwald, Grove Park Road, Chiswick, London, W.
1896. Rothery, William Brockbank, The Muirlands, Kirkby-in-Furness, Lancashire.
1894. Rowe, Daniel, care of Mrs. Rowe, Mount Ambrose, Redruth.
1896. Ruffle, Frank Felingham, Messrs. A. J. Bolton and Co., Jackson Ghat Street, Calcutta, India.
1895. Russell, Frederick, Manager, Gas Works, Bexhill-on-Sea.

1894. Salis, Henry Rodolph de, Ivy Lodge, Iver Heath, near Uxbridge.
1896. Samuel, Blelock Lee, Grahamston Foundry and Engine Works, Barrhead, near Glasgow.
1896. Sangster, Charles, Works Manager, Cycle Components Manufacturing Co., Bournbrook, Birmingham.
1896. Scanlan, Horace Edward, Beaconsfield, Longfleet, Poole.
1893. Schloesser, Robert, care of Messrs. Leman and Co., 51 Lincoln's Inn Fields, London, W.C.: (or care of Adolf Schloesser, 185 Sutherland Avenue, London, W.)

1893. Segundo, Edward Carstensen de, 28 Victoria Street, Westminster, S.W.

1892. Seymour, William Frederick Earl, Engineer's Office, Great Western Railway, Swindon.

1891. Smith, Joseph Philip Grace, Polytechnic School of Engineering, 309 Regent Street, London, W.

1894. Smith, William Arthur, Midland Arches, Northampton; and 18 Albion Place, Northampton. [*Machinery, Northampton.*]

1891. Snell, John Francis Cleverton, Borough Electrical Engineer, Corporation Electricity Station, Sunderland.

1896. Stewart, Charles Nigel, 39 Victoria Street, Westminster, S.W. [*Quiescent, London.*]

1896. Stobart, Henry Gervas, Wolsingham Steel Works, Wolsingham, near Darlington.

1893. Stockton, Joseph Sadler, Works Manager, Loughborough Cycle and Engineering Works, Mill Street, Loughborough.

1894. Stone, Sidney, Metropolitan Railway-Carriage and Wagon Works, Saltley, Birmingham.

1896. Sutherland, James, Manager, Alumina Factory, Larne Harbour, County Antrim, Ireland. [*Aluminium, Larne Harbour.*]

1894. Sutton, Hugh Reginald, Messrs. Mackies, Berks Iron Works, Caversham Road, Reading. [*Mackies, Reading.* 86.]

1896. Swallow, John, Messrs. W. Neill and Son, Bold Iron Works, St. Helen's Junction, Lancashire. [*Neill, St. Helen's.* 20.]

1887. Tabor, Edward Henry, Mill House, Worsley, Manchester.

1893. Takatsuji, Narazo, Superintending Engineer, Calico Weaving Mill, Osaka, Japan.

1895. Takimura, Takeo, General Manager, Osaka Cotton Mill, Osaka, Japan.

1893. Talbot, Frederick William, Engineer and Manager, Water Works, Frimley Green, Farnborough, Hants.

1894. Taylor, William, Messrs. Taylor, Taylor, and Hobson, Slate Street Works, Leicester. [*Lenses, Leicester.* 134.]

1893. Tenney, Dennis, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough.

1893. Thomasson, Lucas, Cotlands, London Colney, St. Albans.

1896. Thompson, Thomas, General Manager, Australasian Gold Trust, Lindsay Street, Coolgardie, Western Australia: (or care of Alfred Thompson 20 Bucklersbury, London, E.C.)

1894. Thomson, Henry, Engineer, Cawnpore Woollen Mills, Cawnpore, India.

1893. Thomson, James Watson, Robert Gordon's College, Aberdeen.

1894. Thorpe, Walter Charles, Messrs. Goddard, Massey and Warner, Traffic Street, Nottingham.

1895. Threlfall, George, 50 Fenchurch Street, London, E.C. [*Gasify, London.*]

1893. Tomes, William Jameson, Oakfield, Belle Vue, Shrewsbury.

1893. Tomlinson, William Augustus, P.O. Box 1978, Johannesburg, Transvaal, South Africa: (or care of John Tomlinson, Birthorpe Manor, Folkingham.)

1896. Trafford, Alfred, Albion Lamp Works (Rippingille's), Birmingham.

1893. Turner, Henry Arthur, care of Arthur Koppel, 96 Leadenhall Street, London, E.C.

1896. Turner, James William, Messrs. George Smith and Co., 13 Commercial Road, Pimlico, London, S.W.

1896. Umney, Herbert Williams, Professor of Engineering, McGill University, Montreal, Canada.

1896. Vallint, Frank William, Superintendent, Mullicks Ghat Pumping Station, Calcutta Water Works, Calcutta, India.

1896. Vernon, William Harry, Messrs. E. Green and Son, Wakefield.

1893. Walker, Charles Christopher, Messrs. Walker, Eaton and Co., Wicker Iron Works, Sheffield. [*Founder, Sheffield.* 376.]

1895. Wasdell, Abel, Superintendent, Water Works, Allahabad, India.

1894. Wasdell, Thomas, Jun., Water Works Road, Edgbaston, Birmingham.

1893. Watson, George, 39 Victoria Street, Westminster, S.W. [*Meterage, London.*]

1893. Wells, Sidney Herbert, Principal, Battersea Polytechnic Institute, Battersea, London, S.W.

1895. West, Charles Herbert, 5 Castle Street, Liverpool. [*Referee, Liverpool.* 5223.]

1895. Wild, Adamson George, care of W. S. Laycock, Victoria Street Works, Sheffield.

1893. Wilkins, George Cornelius, Messrs. Samuelson and Co., Britannia Iron Works, Banbury.

1892. Williams, Arthur Edward, Messrs. Nelson Brothers, Nelson's Wharf, Lambeth, London, S.E.

1895. Williams, Henry Watson, Essex Street, Fremantle, Western Australia.

1889. Willis, Edward Turnley, Hockley Hall and Whateley Colliery, Tamworth.

1890. Winmill, Hallett, P.O. Box 1161, Johannesburg, Transvaal, South Africa: (or care of C. C. Winmill, 114 Main Road, Bexley Heath, S.O., Kent.)

1896. Winston, Harold Holmes, Messrs. Waterlow and Sons, Finsbury, London, E.C.

1896. Wiseman, Alfred, Messrs. Robey and Co., Globe Iron Works, Lincoln; and 45 Princess Road, Edgbaston, Birmingham.

1895. Wort, Walter Edward, Liquid Fuel Engineering Co., Columbine Ship Yard, East Cowes, Isle of Wight.

1889. Wright, Howard Theophilus, Great George Street Chambers, Westminster, S.W. [*Heaterite, London.* 3248.]

ASSOCIATES.

1880. Allen, William Edgar, Imperial Steel Works, Cross George Street, Sheffield.

1881. Barcroft, Henry, Bessbrook Spinning Works, County Armagh, Ireland; and The Glen, Newry, Ireland.

1889. Barr, John, The Glenfield Engineering Works, Kilmarnock.

1886. Bennison, William Clyburn, Messrs. Samuel Osborn and Co., Clyde Steel and Iron Works, Sheffield; and 38 Wellington Street, Higher Broughton, Manchester.

1896. Bentley, Wallace, Royal Insurance Buildings, Crossley Street, Halifax.

1890. Birch, John Grant, 10 and 11 Queen Street Place, London, E.C.

1892. Bowman, Frederic Hungerford, D.Sc., F.R.S.E., Mayfield, Knutsford.

1888. Brown, Harold, Messrs. Linklater, Hackwood, Addison and Brown, 2 Bond Court, Walbrook, London, E.C.

1890. Burt, John Mowlem, Messrs. John Mowlem and Co., 19 Grosvenor Road, Pimlico, London, S.W.

1891. Carter, Frederick Heathcote, 9 Oxford Street, Manchester. [*Girder, Manchester.*]

1889. Castle, Frederick George, East London Technical College, People's Palace, Mile End Road, London, E.

1889. Chamberlain, John George, Messrs. Joseph Wright and Co., Neptune Forge, Tipton.

1888. Chrimes, Charles Edward, Messrs. Guest and Chrimes, Brass Works, Rotherham.

1890. Chubb, Richard, Messrs. Gillison and Chadwick, 10 Tower Buildings, Liverpool.

1893. Clarke, Edward Fuhrmann, Curzon Chambers, Paradise Street, Birmingham; and 59 Stanmore Road, Edgbaston, Birmingham.

1879. Clowes, Edward Arnott, Messrs. William Clowes and Sons, Duke Street, Stamford Street, London, S.E. [*Clowes, London.* 4558.]

1895. Cole, James Conrad, Messrs. Perkin and Cole, 29 Great George Street, Westminster, S.W.

1892. Cooper, Thomas Lancelot Reed, 27 Bothwell Street, Glasgow.

1894. Cowles, Lieut.-Commander William S., U.S.N., 123 Victoria Street, Westminster, S.W.

1892. Cryer, Arthur, University College, Cardiff.

1893. Darlington, John, Engine and Boiler Insurance Co., Manchester; and 3 Marlborough Gardens, Ealing, London, W.

1892. Davis, George Brown, Palace Wharf, Stangate, London, S.E.; and Cambridge House, 242 South Lambeth Road, London, S.W.

1896. Devine, William Henry, Secretary, Mitsu Bishi Engine Works and Dockyard, Nagasaki, Japan.

1895. Docker, Frank Dudley, Messrs. Docker Brothers, Birmingham Varnish Works, Icknield Port Road, Birmingham. [*Japan, Birmingham.* 3522.]

1892. Fauvel, Charles James, Fauvel Gold Recovery Co., Broad Street House, London, E.C.

1891. Foster, George, Hecla Foundry Steel Works, Sheffield; and Lyme Villa, Rotherham.

1889. Golby, Frederick William, 36 Chancery Lane, London, W.C.

1889. Gregory, George Francis, Boarzell, Hawkhurst.

1896. Harvey, Julius, 11 Queen Victoria Street, London, E.C. [*Crosshead, London.*]

1887. Hind, Enoch, Edgar Rise, Nottingham.

1896. Hutton, William, P.O. Box 2399, Johannesburg, Transvaal, South Africa.

1891. Jackman, Joseph, Persberg Steel Works, Pothouse Road, Attercliffe, Sheffield. [*Persberg, Sheffield.* 94.]

1884. Jackson, Edward, Midland Railway-Carriage and Wagon Works, Birmingham. [*Wagon, Birmingham.*]

1896. Kennan, Williams Thomas, Messrs. Kennan and Sons, Fishamble Street, Dublin. [*Kennans, Dublin.*]

1896. King, Benjamin Thomas, 163 Queen Victoria Street, London, E.C. [*Apis, London.* 1682.]

1896. Kitto, William Henry, Morvah, Hartington Road, Grove Park, London, W.

1896. Lemkes, Carl Rudolf Lewin, Messrs. Schäffer and Budenberg, 194 and 196 Hope Street, Glasgow. [*Injector, Glasgow.* 3119.]

1881. Lowood, John Grayson, Gannister Works, Attercliffe Road, Sheffield. [*Lowood, Sheffield.* 131.]

1895. MacBrayne, Laurence, 119 Hope Street, Glasgow.

1886. Mackenzie, Keith Ronald, Gillotts, Henley-on-Thames.

1896. Marshall, Lewis, Messrs. Lumby, Son, and Wood, West Grove Works, Halifax. [*Lumby, Halifax.* 5 A.]

1868. Matthews, Thomas Bright, Messrs. Turton Brothers and Matthews, Phœnix Steel Works, Sheffield. [*Matthews, Sheffield.*]

1890. McGillivray, William, Messrs. Austin McGillivray and Co., Falcon Works, Sheffield. [*Austin, Sheffield.*]

1889. McKinnel, William, 234A Nithsdale Road, Pollokshields, Glasgow.

1890. Meggitt, Samuel Newton, Messrs. Ibbotson Brothers and Co., Globe Steel Works, Sheffield.

1892. Morley, John, Sanitary Engineering Works, Palace Wharf, Stangate, London, S.E.

1896. Naylor, Sam, Messrs. Lumby, Son, and Wood, West Grove Works. Halifax. [*Lumby, Halifax.* 5 A.]

1887. Neville, Edward Hermann, 35 Calle de Alcala, Madrid, Spain.

1874. Paget, Berkeley, Low Moor Iron Office, 2 Laurence Pountney Hill, Cannon Street, London, E.C. [*Gryphon, London.*]

1886. Peacock, William J. P., Wells Street, Oxford Street, London, W.; and 41 St. James' Street, London, S.W.

1888. Peake, Robert Cecil, Cumberland House, Redbourn, near St. Albans.

1887. Peech, Henry, Phœnix Bessemer Steel Works, near Sheffield; and 49 Victoria Street, Westminster, S.W.

1887. Peech, William Henry, Phœnix Bessemer Steel Works, near Sheffield; and Fernbank, Roehampton Park, London, S.W.

1894. Peters, Lindsley Byron, Messrs. G. D. Peters and Co., Moorgate Works, Moorfields, London, E.C. [*Peters, London.*]

1884. Phillips, Richard Morgan (*Life Associate*), 21 to 24 State Street, New York, United States.

1891. Plant, George, Moseley Road School, Birmingham.

1891. Rankin, Thomas Thomson, Principal, Coatbridge Technical School and West of Scotland Mining College, Coatbridge.

1892. Reed, Ernest Charles, Riverside Mills, Dartford.

1891. Rowcliffe, William Charles, 1 Bedford Row, London, W.C.

1888. Rowell, John Henry, New Brewery, High Street, Gateshead.

1896. Sangster, William Skene, Superintendent, Lima Water Works, Lima, Peru.

1890. Schofield, John William, Messrs. Gregory and Bramall, Soho Steel and File Works, Sheffield.

1887. Scott, Walter, Victoria Chambers, Grainger Street West, Newcastle-on-Tyne. [*Contractor, Newcastle-on-Tyne.*]
1893. Simpson, Edward Percy, Messrs. Simpson and Co., 101 Grosvenor Road, Pimlico, London, S.W.
1891. Spencer, Francis Henry, P.O. Box 1338, Johannesburg, Transvaal, South Africa.
1892. Stead, John Edward, 11 Queen's Terrace, Middlesbrough. [*Stead, Middlesbrough.*]

1890. Taylor, John, 99 and 101 Fonthill Road, Finsbury Park, London, N.; and Stockport.
1896. Taylor, Joseph Henry, 9 and 11 Fenchurch Avenue, London, E.C. [*Tyne, London.* 4108.]
1887. Tozer, Edward Sanderson, Phœnix Bessemer Steel Works, near Sheffield.

1893. Wadham, Arthur, 171 Queen Victoria Street, London, E.C. [*Wadham, London.*]
1892. Whitehead, Richard David, Municipal Technical College, Green Hill, Derby.
1883. Williamson, Robert S., Cannock and Rugeley Collieries, Heduesford, near Stafford.
1891. Wiseman, Edmund, Cheapside and John Street, Luton. [*Wiseman, Luton.*]

GRADUATES.

1892. Adams, Sidney Rickman, Consolidated Gold Fields of South Africa, P.O. Box 67, Johannesburg, Transvaal, South Africa: (or care of Henry Adams, 3 Colville Square, Bayswater, London, W.)

1885. Addis, Frederick Henry, District Locomotive Superintendent, Rajputana-Malwa Railway, Sirsa, Punjaub, India: (or care of Messrs. Grindlay and Co., 55 Parliament Street, London, S.W.)

1895. Alcock, Alfred Edwin, Yorkshire Engine Works, Sheffield.

1893. Alderson, Charles Albert Heselton, Messrs. Ruston Proctor and Co., Sheaf Iron Works, Lincoln; and 13 Cheviot Street, Lincoln.

1894. Ambrose, Sewell Powis, 56 Vyse Street, Birmingham.

1882. Anderson, William, Locomotive Department, North Eastern Railway, Gateshead.

1890. Aubin, Percy Adrian, 29 St. James' Street, St. Helier's, Jersey.

1894. Aylesbury, Thomas Antram, 11 Almeric Road, New Wandsworth, London S.W.

1888. Bailey, Wilfred Daniel, Empresa Carlos Bright, 874 Calle Cuyo, Buenos Aires, Argentine Republic.

1894. Barber, Edward Whitley, 11 Portland Grove, Fallowfield, Manchester.

1896. Barbosa, Agenor, Juiz de Fora, Minas Geraes, Brazil.

1889. Barrow, Arthur Robert Maclean, care of Messrs. William Watson and Co., 28 Apollo Street, Bombay, India: (or care of Mrs. Barrow, Holly Grove Fittleworth, Pulborough.)

1893. Bedbrook, James Albert Harvey, Haresfield, Blenkarne Road, Wandsworth Common, London, S.W.

1888. Bell, Alexander Dirom, care of W. S. Bell, East Fortoun, Drem Haddingtonshire.

1884. Bell, Robert Arthur, Assistant Locomotive and Carriage Superintendent South Indian Railway, Negapatam, Madras, India: (or care of Mrs. R. C. Bell, 30 Egerton Crescent, London, S.W.)

1890. Bell, William Thomas, Mulgrave, St. Catherine's, Lincoln.

1896. Bigger, Courtenay, Falmore Hall, Dundalk, Ireland.

1895. Blair, George, 16 Albert Road (East), Crosshill, Glasgow.

1888. Bradley, Arthur Ashworth, Princess Estate and Gold Mining Co., Roodepoort, near Johannesburg, Transvaal, South Africa: (or care of Rev. Gilbert Bradley, St. Edmund's Vicarage, Dudley, Worcestershire.)

1887. Bremner, Bruce Laing, 1 Towcester Road, Far Cotton, Northampton.
1894. Britten, Thomas, Electric Construction Company, Wolverhampton.
1890. Brousson, Robert Percy, Westinghouse Electric Manufacturing Co., East Pittsburg, Pennsylvania, United States.
1880. Buckle, William Harry Ray, 11 Billiter Buildings, 49 Leadenhall Street, London, E.C.
1892. Bulwer, Ernest Henry Earle, Messrs. George Fletcher and Co., Poplar Iron Works, King Street, Poplar, London, E.
1891. Butcher, Walter Edward, 100 Lewisham Road, Lewisham, London, S.E.

1891. Caswell, Charles Henry, 4 Trewsbury Road, Sydenham, London, S.E.
1894. Cater, John McIlvaine, Southdown, The Downs, Wimbledon.
1889. Challen, Walter Bernard, Messrs. Taylor and Challen, Derwent Foundry, 60 and 62 Constitution Hill, Birmingham.
1890. Chatwood, Arthur Brunel, Chatwood's Safe and Lock Co.. 76 Newgate Street, London, E.C. [*Chatwood, London.* 6835.]
1891. Church, Harry, Ingeniero, para la Colonia San Gustavo, La Paz, Entre Rios, South America: (or care of George Church, Willington, Bedford.)
1895. Clarke, Leigh Theophilus, Atlingworth, Beckenham.
1892. Cleverly, William Bartholomew, Messrs. John Brown and Co., Perseverance Works, 6 Bow Common Lane, London, E.
1892. Collingridge, Harvey, Messrs. S. Pearson and Son, Blackwall Tunnel Works, East Greenwich, London, S.E.; and Ingleborough, The Ridgway, Enfield.
1895. Connell, William Percival, Calle Sanz 14, Minas de Rio Tinto, Huelva, Spain: (or care of W. G. Connell, 83 Cheapside, London, E.C.)
1889. Cook, George Norcliffe, Messrs. Thomas Firth and Sons, Norfolk Works, Sheffield.
1896. Crow, Lewis, 85 High Street, Lewisham, London, S.E.
1891. Cutler, Samuel, Jun., Messrs. Samuel Cutler and Sons, Providence Iron Works, Millwall, London, E.

1894. Darwood, John William, Ahlone, Rangoon, Burma.
1896. Davson, Stephen Frederick, 203 Maida Vale, London, W.
1896. Dawe, John Nanscawen, Bank House, Wadebridge, Cornwall.
1884. Dixon, John, Eastwood Villa, Lytham, near Preston, Lancashire.

1893. Douglas, William Saunders, Consett Iron Works, Consett, R.S.O., County Durham; and 60 Durham Road, Blackhill, R.S.O., County Durham.
1895. Dresser, Charles, 5 Marius Road, Balham, London, S.W.
1896. Dryden, William, Jun., Grimshaw Street Foundry, Preston.
1891. Duncan, Martin Gordon, Lexden, 63 Elmfield Road, Upper Tooting, London, S.W.

1896. Edwards, James George Benjamin, Wintringham Higher Grade Organised Science School, Grimsby.

1895. Ferguson, Victor Bruce, Altidore Villa, Pittville, Cheltenham.
1896. Fiegehen, Edward George, Bedford Engineering Works, Bedford.
1893. Fox, Frederick Joseph, 102 Fenchurch Street, London, E.C.
1895. Fryer, Tom Jefferson, Totley Brook, near Sheffield.

1895. Gale, Robert Henry, 38 Scarsdale Villas, Kensington, London, W.
1890. Garrett, Frank, Jun., Messrs. Richard Garrett and Sons, Leiston Works, Leiston, R.S.O., Suffolk.
1895. Gill, Charles Edgar, 9 Balmoral Place, Halifax.
1896. Goddard, William Herbert, Pinkthorne, Canning Road, Addiscombe, Croydon.
1896. Gordon, Leslie, Bentley Priory, Stanmore.
1895. Griffith, Charles Leopold Troyte, Messrs. Bramwell and Harris, 5 Great George Street, Westminster, S.W.
1895. Griffiths, Alfred, Messrs. Thomas Guest and Co., Phœnix Iron Works, Poland Street, Oldham Road, Manchester.

1895. Hall, William Brasier, H.M.S. "Impérieuse," Pacific Station: (or Inglewood, Christ Church Road, Cheltenham.)
1894. Halsey, Charles Turner, Womersley House, Dickenson Road, Hornsey, London, N.
1889. Hayward, Robert Francis, Salt Lake and Ogden Gas and Electric Light Co., Salt Lake City, Utah, United States.
1877. Heaton, Arthur, Messrs. Heaton and Dugard, Metal and Wire Works, Shadwell Street, Birmingham. [*Heagard, Birmingham.*]
1874. Hedley, Thomas, Room 20, Sherlock Building, Portland, Oregon, United States.
1893. Heinrich, Herbert Rodolph, 17 Buckingham Palace Road, London, S.W.

1894. Hodges, Frank William, Messrs. Thomas Cook and Son, Cairo, Egypt ; and Tullgarn, 37 Cromwell Road, West Brighton, Brighton.

1896. Hodgson, George Henry, Sulphide Corporation, Cockle Creek, New South Wales.

1891. Hodgson, William James, Messrs. Hodgson and Hodgson, Central Chemical Works, Nottingham.

1887. Hogg, William, Craigmore, Blackrock, Dublin.

1889. Hosgood, Thomas Watkin, Sketty, near Swansea.

1891. Hosgood, Walter James, Locomotive Department, Barry Dock and Railways, Barry, near Cardiff.

1889. Hosken, Arthur Fayrer, care of Rev. R. F. Hosken, 12A Charterhouse Square, London, E.C.

1889. Howard, Geoffrey, Britannia Iron Works, Bedford.

1883. Howard, Harry James, Messrs. Colman's Mustard Mills, Carrow Works, Norwich.

1891. Hughes, Edward Sinclair Bremner, 16 Court Road, West Norwood, London, S.E.

1896. Humphrey, Frederick George, 166 High Street, Sevenoaks.

1894. Ironside, William Allan, Messrs. Ironside Son and Co., 1 Gresham Buildings, Guildhall, London, E.C.

1896. Johnson, Henry Howard, care of Frank Johnson, Sea Point, Cape Town, Cape Colony.

1894. Johnson, Walter Wroe, Castleton Foundry and Engineering Works, Armley Road, Leeds.

1890. Jones, Arthur Dansey, Locomotive Department, Lancashire and Yorkshire Railway, Horwich, near Bolton.

1891. Jordan, Frederic William, 42 Wells Street, Mortimer Street, Cavendish Square, London, W.

1889. Joy, Basil Humbert, 85 Gracechurch Street, Westminster, S.W., and 118 Broadhurst Gardens, West Hampstead, London, N.W.

1895. Keen, Harry A., Patent Nut and Bolt Co., London Works, near Birmingham.

1896. Kitsell, Archibald Edward, 24 St. Stephen's Avenue, Shepherd's Bush, London, W.

1896. Knight, Stephenson Yates, Messrs. Thomas Middleton and Co., Loman Street, Southwark, London, S.E.

1883. Lander, Philip Vincent, Woodside House, Wimbledon : (or care of W. W Lander, Imperial Ottoman Bank, 26 Throgmorton Street, London, E.C.)

1894. Larmuth, William Oliver, Messrs. Thomas Larmuth and Co., Todleben Iron Works, Unwin Street, Cross Lane, Salford, Manchester; and 48 Fitzwarren Street, Pendleton, Manchester.

1881. Lawson, James Ibbs, Resident Engineer, New Zealand Railways, Wanganui, New Zealand.

1886. Lewis, William Thomas, Jun., Engineer's Office, Bute Docks, Cardiff; and Dalemain, Llandaff Yard, near Cardiff.

1894. Lloyd, Thomas Zachary, Messrs. Nettlefolds, Smethwick, Birmingham; and Areley Hall, Stourport.

1883. Mackenzie, Thomas Brown, Messrs. J. Copeland and Co., Pulteney Street Engine Works, Glasgow; and 342 Duke Street, Glasgow.

1893. Mackesy, Walter, 20 Suffolk Street, Jarrow.

1895. Maia, Honorio de Araujo, Rua Municipal 17, Rio de Janeiro, Brazil.

1894. Mansfield, Walter, Messrs. Edwin Mansfield and Sons, 140 Great Clowes Street, Broughton, Manchester. [*Gaslight, Manchester.*]

1868. Mappin, Frank, Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield.

1892. Marks, Alfred Pally, 155 Adelaide Road, London, N.W.

1895. Marriner, John, 9 Gloucester Place, Greenwich, London, S.E.

1889. Marshall, Frank Theodore, Messrs. R. and W. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.

1896. Marshall, John Frederick, King's College, Cambridge.

1888. Marten, Hubert Bindon, Contractor's Office, Metropolitan Railway Widening, 50 Iverson Road, London, N.W.; and Pedmore, Stourbridge.

1886. Mattos, Alvaro Gomes de, 98 Rua da Sande, Rio de Janeiro, Brazil: (or care of Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.)

1892. Miles, Frederick Hudson, Hampden House, Phœnix Street, St. Pancras, London, N.W.

1891. Mills, Matthew William, Moss Foundry, Heywood, near Manchester.

1891. Mogg, Henry Hodges, Newbridge Hill, near Bath.

1894. Moon, Edgar Rupert, Locomotive Superintendent, Midland Railway of Western Australia, St. George's Terrace, Perth, Western Australia: (or care of J. E. Moon, Cloudesleigh, Brixton, near Plymouth.)

1896. Morton, John Henry, 8 Deacon Street, New Swindon, Swindon.

1892. Murray, David James, Thorn House, Johnstone, near Glasgow.

1883. O'Connor, John Frederick, Messrs. O'Connor and Rutherford, 31 and 33 Broadway, New York, United States.

1883. Osborn, William Fawcett, Messrs. Samuel Osborn and Co., Clyde Steel and Iron Works, Sheffield.

1883. Palchoudhuri, Bipradas, Moheshgunj Factory, Krishnugher, Bengal.
1895. Palmer, Henry Boswell. Jun., Heathfield Lodge, Gunnersbury Lane, Acton, London, W.
1887. Paterson, John Edward, Chief Mechanical Engineer's Office, New South Wales Government Railways, Wilson Street, Eveleigh, Sydney, New South Wales.
1895. Pearce, Herbert, Linotype Depôt, Castle Street, Endell Street, Long Acre, London, W.C.
1894. Petter, Percival Waddams, The Foundry, Yeovil.
1890. Philipson, John, Jun., Messrs. Atkinson and Philipson, 27 Pilgrim Street, Newcastle-on-Tyne. [*Carriage, Newcastle-on-Tyne.* 415.]
1884. Philipson, William, Messrs. Atkinson and Philipson, 27 Pilgrim Street, Newcastle-on-Tyne. [*Carriage, Newcastle-on-Tyne.* 415.]
1896. Pinel, Paul Gustave Marie, Messrs. Lethuillier and Pinel, 24 bis Rue Méridienne, Rouen, France.
1890. Powell, Frederick, York House, Malvern Link, Malvern.
1892. Power, Arthur Cyril, 17 Fordwych Road, Brondesbury, London, N.W.
1893. Price, William Frederick, Wyresdale, Wilbraham Road, Chorlton-cum-Hardy, Manchester.

1892. Ransom, Herbert Byrom, Messrs. Manlove Alliott and Co., 57 Gracechurch Street, London, E.C.
1895. Read, George Henry, 7 Palmerston Road, Bowes Park, London, N.
1894. Readhead, Robert, Jun., Messrs. John Readhead and Sons, West Docks, South Shields.
1892. Redfern, Charles George, 4 South Street, Finsbury, London, E.C.
1884. Reynolds, Thomas Blair, 28 Victoria Street, Westminster, S.W.
1895. Riches, Carlton Tom Hurry, 8 Park Grove, Cardiff.
1894. Richmond, William Frederick, Longton Iron Works, Staffordshire; and Shellness, Stradella Road, Herne Hill, London, S.E.
1892. Ridley, James Cartmell, Jun., 3 Summerhill Grove, Newcastle-on-Tyne.
1895. Roberts, Basil Owen, Cooper Steam Digger Co., King's Lynn.
1896. Rosevere, Gerald Rhodes, Great Western Railway, Stafford Road Works, Wolverhampton; and care of W. S. Rosevere, The Manor House, Tavistock, Devon.
1896. Rothschild, Lester Vivian, Messrs. Fraser and Chalmers, Erith, S.O., Kent.
1884. Roux, Paul Louis, 54 Boulevard du Temple, Paris.
1888. Rümmele, Alfredo, 17 Via Principe Umberto, Milan, Italy.

1894. Russell, William Colin, Gwalia Tin-Plate Works, Briton Ferry; and Hafod, Swansea.

1890. Saxelby, Herbert Raffaelle, 7 and 8 Ironmonger Lane, Cheapside, London, E.C.
1892. Scarfe, George Norman, care of George Scarfe, Gawler Place, Adelaide, South Australia.
1881. Scott, Ernest, Messrs. Ernest Scott and Mountain, Close Works, Newcastle-on-Tyne. [*Esco, Newcastle-on-Tyne.* 432.]
1893. Sharpley, George Ruston, St. Giles' Avenue, Lincoln.
1892. Shepherd, James Horace, Great Western Railway, Swindon.
1887. Simkins, Charles Wickens, Jun., Amguri Tea Estate, Amguri Post Office, Sibsagar, Assam, India: (or care of Charles W. Simkins, The Lodge, Lowdham, near Nottingham.)
1894. Simpson, Lightly Stapleton, Trinity College, Cambridge; and 16 Kent Terrace, Regent's Park, London, N.W.
1896. Simpson, Norman De Lisle, Messrs. George Fletcher and Co., Masson Works, Litchurch, Derby.
1894. Skinner, Russell Foster, 14 Hugh Street, Belgrave Road, London, S.W.; and 6 Cambridge Road, Brighton.
1895. Smith, Frederick Hardcastle, Steam Crane Works, Old Foundry, Rodley, near Leeds.
1895. Southward, Philip Edmond, P.O. Box 2661, Johannesburg, Transvaal, South Africa: (or care of John Southward, 11 Frederick Crescent, Brixton, London, S.W.)
1892. Stokes, Frank Torrens, P.O. Box 1355, Johannesburg, Transvaal, South Africa.
1894. Suffield, Frank Wilson, Glen Lyn, Grove Avenue, Moseley, Birmingham.
1883. Swale, Gerald, Westminster Palace Hotel, 4 Victoria Street, Westminster, S.W.

1885. Tangye, John Henry, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham.
1884. Taylor, Joseph, Norville, Eaton Road, Heaton Chapel, near Stockport.
1884. Taylor, Maurice, 39 Rue de Lisbonne, Paris.
1896. Thom, Frank, Messrs. Yates and Thom, Canal Foundry, Blackburn.
1894. Thorpe, Wilfred Bertram, 20 Larkhall Rise, Clapham, London, S.W.
1895. Titren, Gerald Ernest de Keyser, Natal Government Railway Works, Durban, Natal.

1891. Vaizey, John Leonard, Locomotive Department, Great Eastern Railway, Norwich.

1892. Vezey, Albert Edward, Electrical Department, London and North Western Railway Works, Crewe.

1888. Waddington, Samuel Sugden, 35 King William Street, London Bridge, London, E.C.
1885. Wakefield, William Marsden, Messrs. John King and Co., 30 Strand Road, Calcutta, India.
1896. Walker, Charles Bell, Messrs. John Holroyd and Co., Milnrow, near Rochdale.
1888. Waring, Henry, Engineer, Dublin Laundry Co.. Milltown, near Dublin.
1892. Warton, Richard George Frank, Westerleigh, Llandaff, near Cardiff.
1895. Waugh, Hylton Norman Drake, Locomotive Department, London Brighton and South Coast Railway, Brighton.
1886. Wesley, Joseph A., Messrs. Woodhouse and Rixson, Chantrey Steel and Crank Works, Sheffield.
1888. Whichello, Richard, Messrs. Max Nothmann and Co., Rio de Janeiro, Brazil: (or 44 Trumpington Street, Cambridge.)
1894. Whitelegg, Robert Harben, Locomotive Department, London Tilbury and Southend Railway, Plaistow, London, E.
1889. Wigham, John Cuthbert, Electric Light Station, Shrewsbury.
1895. Wilkin, Ernest Vivian, Northumberland Engine Works, Wallsend-on-Tyne; and 11 Appold Street, Finsbury, London, E.C.
1896. Williams, Llewellyn Wynn, Railway Appliances Works, Cathcart, Glasgow.
1890. Wilson, Alexander Cowan, Manchester Sheffield and Lincolnshire Railway, The Newarke, Leicester; and Osgathorpe Hills, Sheffield.
1896. Winlaw, William Willoughby, Sir W. G. Armstrong, Mitchell and Co. Elswick Works, Newcastle-on-Tyne.
1887. Wrench, John Henry Kirke, 173 West Huron Street, Chicago, United States: (or care of E. M. Wrench, Park Lodge, Baslow, Chesterfield.)
1890. Wright, William Carthew, General Post Office, Melbourne, Victoria: (or care of Dr. Gaskoin Wright, 253 Eccles New Road, Salford, Manchester.)

1895. Yeames, James Lamb, 18 Bishopsgate Street Within, London, E.C.
1891. Yerbury, Frederick Augustus, 17 Victoria Street, Westminster, S.W.

Institution of Mechanical Engineers.

PROCEEDINGS.

July 1896.

The Summer Meeting of the Institution was held in Belfast, commencing on Tuesday, 28th July 1896, at Ten o'clock a.m.; E. Windsor Richards, Esq., President, in the chair.

The President, Council, and Members were received in the Examination Hall of Queen's College by the Right Honourable the Lord Mayor, Alderman W. J. Pirrie, J.P., and the Chairman and Members of the Reception Committee.

The Lord Mayor said it was with feelings of the greatest pleasure that he welcomed the President and Members of the Institution of Mechanical Engineers to Belfast; and it was particularly gratifying to himself that he should be Lord Mayor of the City when an Institution of such importance to the engineering profession—an Institution of which he himself was a Member—had decided to hold their Summer Meeting here. Eight years ago the Members had paid a hurried visit of one day to Belfast, after meeting in Dublin; but the present was the first time that the Institution had held a meeting in Belfast. It was gratifying to him that he now had the honour of welcoming the Members, not only for the personal consideration he had mentioned, but also because he regarded their presence as a recognition by one of the leading institutions of the importance and fame of the City of which Belfastmen were all so proud, and which they believed was destined to take yet a still higher place amongst the great cities of the kingdom. On his own account therefore, and on behalf of the citizens of Belfast, he extended a very hearty welcome to the Members of the Institution of Mechanical Engineers.

(The Lord Mayor.)

While it was unnecessary for him to enter at any length upon the many subjects of special interest to engineers which would engage their attention during their stay in Belfast, it would not be out of place if he were to refer briefly to the great progress that had been made of late years in the various branches of engineering, to the position of their profession at the present time, and to its prospects for the future. The advancement in engineering science and mechanical skill during the last fifty years had been similar, and had materially contributed, to the remarkable developments which had made the reign of Queen Victoria the most illustrious of any of either her predecessors or her contemporaries. But if, instead of fifty years, they looked back over only the last twenty or ten years, and considered the wonderful strides made in engineering during this shorter period, they saw that the history of their profession was still more remarkable. The rapid advance of engineering had accelerated the progress of every other branch of industry and trade. Everything had been revolutionised both on sea and on land; and, thanks to the wonderful changes which had succeeded one another with unfailing regularity and startling rapidity, labour had been economised, work had been cheapened, new channels of industry had been opened up, distant lands had been brought nearer in point of time, and the whole world had been benefited and enriched. Manufacturers were apt to compare the present high rate of wages with that existing years ago, and to feel occasionally the burden was great; but it should be remembered that, although wages were now higher, yet most articles could now be produced at an actually lower cost for labour than in those good old times to which some seemed to wish to return. As they reviewed the successive stages of progress and development, engineers could not but feel proud of their profession; and while it was satisfactory to remember that all branches of engineering had participated in the forward movement, they specially noticed the great strides which had been made in marine engineering, and also in the application of electrical power, the latter being perhaps the most remarkable of all, because the most recent. The subject which naturally was uppermost in his own mind, on account of his intimate connection with shipbuilding, was the unprecedented advance and improvement in the type and size of steamers, and in their mechanical construction. The improvement consisted in larger carrying power, enabling the vessels to make money even at lower rates of freight, and in reduction of weight in the construction, while at the same time the strength of the structure was increased; and, bearing more directly on the subject of engineering, would be noted the successive improvements in the machinery, from compound engines to triple-expansion and from triple to quadruple-expansion, while the higher steam-pressure effected great economy in the consumption of fuel: and at the present moment he was sure many of the engineers in the country were dreaming of water-tube boilers and various other devices, for still further reducing the weight of machinery on board vessels. All these subjects were of the highest importance, and each of them might well furnish materials for a series of papers, and no doubt they would all come up for discussion in due course. They possessed a special interest for himself and many others of the inhabitants of Belfast, who would follow closely the proceedings of the Institution this week. Never did the engineering profession stand so high both in honour and achievement as at the present time. The triumphs of mechanical skill and ingenuity were astounding, and the history of the last few years was highly creditable and satisfactory to British engineers. While recognising and appreciating the contributions made by men of other nations to the general progress, it was particularly gratifying that in this, as in many other branches of practical knowledge and commercial enterprise, the British nation was still predominant and in the fore-front, if not always in invention, certainly in the perfecting and application of engineering science. If however the past had witnessed such vast changes, and the present attainments were so satisfactory, what should be said about the future? With many of the improvements to which he had referred being still further developed, with a progressive movement in every branch of the profession, and with new trades springing up, they could not but feel that they were on the eve of greater changes than any which had yet been brought about, and that the developments of

(The Lord Mayor.)

the next few years would astonish even engineers themselves. Amongst the trades now being opened up, not the least important to engineers was that in automobiles. There was a great future he believed for horseless carriages of all descriptions in this country. It was much to be regretted that at present this trade should be hindered, and English engineers be handicapped, by an old act of parliament, which should have been repealed long ago. The restriction he trusted would speedily be removed, when he had no doubt many of the younger engineers would apply themselves to the study of this subject, and a large industry would spring up, giving employment to a vast number of mechanics and others; and he trusted that many of the old established engineering firms in Belfast and other places would be prepared to take advantage of the great demand for autocars of good design and construction, which was sure to arise immediately the existing legislative difficulty was out of the way. From a national point of view it was also a matter for regret that so large a quantity of machinery of the lighter class had still to be imported, such as sewing machines, electric fittings, farming implements, cycles, etc.; and he could not help feeling that even in such manufactures this country ought to be able to compete successfully with a country where the import duties were so high, and living was so dear, and where consequently labour had such a fictitious value, as in America. This he believed could be done if thought and energy were applied to it; and he trusted that in this respect there would be much cause for gratification in the near future.

The present visit of the Institution he trusted would be pleasant and enjoyable to all, and that the deliberations at the meeting would prove a stimulus to many, and contribute much to the advancement and development of engineering science, for which he thought little prophetic power was necessary to predict a brilliant and eventful future.

Mr. WALTER H. WILSON said that, having the honour of occupying the position of Chairman of the Reception Committee, he had great pleasure in following the Lord Mayor in welcoming the

Institution to Belfast on the occasion of what was really their first visit to the City. Their previous short visit might be described in mining parlance as having been in the nature of "prospecting;" and it had then been seen how much interest might attach to a regular meeting of the Institution in Belfast, and he was glad that the time had now arrived for this to be carried out. It gave all who met an opportunity of making new friends, of which they were all glad to avail themselves. It was highly important he considered that all engaged in engineering should have a connecting link with the sister country; and in no way could this object be better accomplished than by such a meeting as the Members were now entering upon. He greatly regretted the illness of the Secretary, of whose assistance he had been glad to take advantage; although not able to be present, he had sent a most capable representative. The duties of the Reception Committee had been of the lightest and pleasantest character, owing to the assistance they had received first from the Secretary before his illness, and subsequently from his substitute. Such visits as that which the Institution was now making were intended to encourage, and did encourage, the Members generally; and he hoped the present visit would result in an increase in the membership. The papers read before the Institution were of high practical value; a single year's volume of the Proceedings contained information of the greatest interest, and thoroughly up to date; the latter was a quality of great importance at the present day. As far as engineering was concerned, the industries of Belfast did not extend back to more than a hundred years. Less than a century ago the flax manufacture was really the entire industry of the district; and in those days looms driven by hand and foot were the means adopted for manufacturing cloth throughout the country. Engineering afterwards stepped in, and such firms sprang up as that of Victor Coates, the great-grandfather of the present directors of the firm bearing his name, whom he regarded as the father of engineering in this part of the world, not so much however in the manufacture of flax machinery as in making engines; this class of work had been carried out at the Lagan Foundry with a marvellous degree of excellence, considering the difficulties which

(Mr. Walter H. Wilson.)

had had to be contended with. It might not be known to every one that this firm had built the very first iron steamer made in Ireland; and theirs was still the leading foundry of large size in Belfast. Although they had now dropped shipbuilding and had handed it over to his own firm—Messrs. Harland and Wolff—they were still carrying on the engineering branch in a spirited way; the Members would have the opportunity of visiting some of their shops, where they would see how much talent had been devoted to the manufacture of machinery. The whole history of mechanical work in Belfast had been altered with the change in the flax trade; and some of the papers announced for reading at this meeting would no doubt give an idea of the various developments which had been effected. One of these was the method of rope-driving, of which good illustrations would be seen here; Messrs. Combe, Barbour, and Combe, who were its originators, had carried it out more than anyone else, and an excellent method it was. A curious relic of the original linen industry yet remained in Donegall Street, where there was an old yard, grass-grown, with what looked like tombstones planted about; it was the old Brown Linen Hall, founded in 1773, to which people formerly brought from the country their brown linens to be sold. This piece of ground, which was now in the hands of trustees and would be valuable as a building site, was still opened once a week; a web of sacking was laid upon one of the tombstones, for any business that was supposed to go on; the attendants were there; and visitors walked in and out again; he had himself been there once to witness the quaint performance, which had now become a farce at the end of the nineteenth century. After the Brown Linen Hall had died a natural death, its place had been taken by the White Linen Hall, erected in 1784 in Donegall Square, which however had lately been removed; and on that central site of five acres a handsome building was now about to be erected as a new Town Hall, in which he hoped the present Lord Mayor would take his seat, if he should remain two or three years longer in office. Favoured by fine weather, he trusted that by means of the arrangements and excursions which had been organized by the Reception Committee, through the kindness of the railway and steamboat companies, the Members of the Institution would be enabled to enjoy themselves during the week. He trusted also that the present visit would only be the precursor of others yet to follow; and that after the Institution had visited a few other cities they would come here again, at a time when the Lord Mayor would be able to show them that another step in advance had been made. The Reception Committee all felt honoured by the presence of the Institution in Belfast, and hoped that the Members generally would carry away pleasant recollections of their visit.

The PRESIDENT desired to thank the Lord Mayor and Mr. Wilson for their kind words of welcome, and for the great cordiality of the reception they had accorded to the Institution. The Members of the Institution were very grateful to the Lord Mayor, seeing that in the midst of his manifold and onerous duties as Chief Magistrate of the City he had given his valuable time and used his great influence to make their visit both profitable and pleasurable. They were also indebted to Mr. Wilson and the Reception Committee for having arranged a programme which opened to their inspection establishments representing the vast industries that had made Belfast famous among the cities of the empire. The Committee had also not forgotten to include in the programme arrangements which would render their visit one of much enjoyment. They further thanked the Belfast engineers for having contributed five papers out of the seven announced for the present meeting; while all the seven had reference to works in Belfast and the neighbourhood. When the Dublin meeting was held in 1888, a short visit had been paid to Belfast, as already mentioned; and several members had then expressed a great desire that one of the summer meetings should be held in this City. Last year an invitation had been received, which the Council most gladly accepted. The members generally he was sure reciprocated the sentiments expressed by the Chairman of the Reception Committee, and hoped for their part that they might make not only new friends but lasting friendships. It would therefore be fully understood how highly he appreciated the cordiality of the welcome accorded to the Institution. He desired to acknowledge most gratefully all that had been done to render their visit agreeable,

(The President.)
and the gracious reception of the Institution by the Lord Mayor and their friends in Belfast.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The PRESIDENT said the Members would be sorry to hear of the serious illness of the Secretary, who had been taken suddenly ill six weeks ago in consequence of over-work, and was still confined to the house; and he was sure they all sympathised with Mr. and Mrs. Bache in this trial. The Council trusted he might eventually get better, or recover entirely. Meanwhile he would be represented at this Meeting by his assistant, Mr. Chapman, as acting secretary.

The Members also sympathised most sincerely he was sure with the Lord Mayor and Mr. Walter H. Wilson, and with their firm of Messrs. Harland and Wolff, as well as with Messrs. Workman, Clark, and Co., in the misfortune that had befallen them through the great fire, which on Sunday night had wrought such destruction in their shipbuilding and engineering establishments.

The PRESIDENT announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and the following fifty-nine candidates were found to be duly elected:—

MEMBERS.

BATEMAN, JAMES THOMAS, . . .	Birkenhead.
BLACK, PETER BLAIR, . . .	London.
BROADFOOT, ANDREW WILSON, . .	Albany, W. Australia.
BROCKLEHURST, GEORGE, . . .	Barbados.
BUCKWELL, GEORGE WILLIAM, . .	Liverpool.
CHAMBERS, ROBERT MARTIN, . .	Belfast.
CLARK, GEORGE, JUN., . . .	Sunderland.
CRAIG, ALEXANDER, ...	Londonderry.
DAY, CHARLES, ...	Bradford.
DOBSON, ADAM, ...	Belfast.

German, Walter Hussey,	Sydney.
Johnston, James,	Brighton.
Kwang, Kwong Yung,	Tientsin.
Moffatt, Alexander Charles,	London.
Patchell, William Henry,	London.
Spring, Francis Joseph Edward, C.I.E.,	Shillong, Assam.
Stirling, Patrick,	Doncaster.
Taylor, William Isaac,	London.

ASSOCIATE MEMBERS.

Abady, Jacques,	London.
Atkinson, Frederic,	London.
Barba, Alfonso G.,	London.
Baron, James Thomas,	London.
Blumfield, Thomas William,	Coventry.
Butcher, Malcolm Henry,	London.
Carolin, Edward Marlay,	Bloemfontein.
Clare, Ernest,	London.
Dawson, Philip,	London.
Fforde, William John,	Belfast.
Firth, John,	Hull.
Fowler, Henry,	Horwich.
Fraser, Frank Hazell,	London.
Garratt, James Herbert,	Colombo.
Garrett, Easton,	Buenos Aires.
Given, Ernest Cranston,	Philadelphia.
Goffe, Edward,	Kimberley.
Grant, William,	Belfast.
Hawes, David Marc Andrew Graham,	London.
Iden, George,	Brighton.
Kerr, Alfred Ernest Campbell,	Ballarat.
Martin, George Best,	Birmingham.
New, Alfred Wilmot,	Coolgardie.
Newell, Ernest,	Bradford.
Pollard, Ferdinand Joseph,	Johannesburg.
Rieter, E. Henry,	Winterthur.

Ruffle, Frank Felingham,	Calcutta.
Sangster, Charles,	Birmingham.
Sutherland, James,	Larne Harbour.
Thompson, Thomas,	Coolgardie.
Vernon, William Harry,	Wakefield.
Winston, Harold Holmes,	London.

ASSOCIATES.

Bentley, Wallace,	Halifax.
Kennan, Williams Thomas,	Dublin.

GRADUATES.

Bigger, Courtenay,	Dundalk.
Dryden, William, Jun.,	Ulverston.
Marshall, John Frederick,	Cambridge.
Morton, John Henry,	Manchester.
Rosevere, Gerald Rhodes,	Wolverhampton.
Rothschild, Lester Vivian,	Erith.
Walker, Charles Bell,	Rochdale.

The following Papers were then read and discussed:—

"Flax Scutching and Flax Hackling Machinery"; by Mr. John Horner, of Belfast.

"Electric Lighting in Belfast"; by Mr. Victor A. H. McCowen, Electrical Engineer to the Belfast Corporation.

At One o'clock the Meeting was adjourned to the following morning.

The Adjourned Meeting was held in Queen's College, Belfast, on Wednesday, 29th July 1896, at Ten o'clock a.m.; E. Windsor Richards, Esq., President, in the chair.

The Discussion upon Mr. McCowen's Paper on Electric Lighting in Belfast was resumed and concluded.

The following Papers were then read and discussed:—

"Unusual Corrosion of Marine Machinery"; by Mr. Hector MacColl, of Belfast.

"Notes on the introduction and development of Rope Driving"; by Mr. Abram Combe, of Belfast.

"Description of the Alumina Factory at Larne Harbour"; by Mr. James Sutherland, Manager.

"Description of the Belfast Gas Works"; by Mr. James Stelfox, Engineer and Manager.

The remaining Paper announced for reading and discussion was adjourned to a subsequent meeting.

The President proposed the following Votes of Thanks, which were passed with applause:—

To the Right Honourable the Lord Mayor and the Lady Mayoress, for their hospitable invitation of the Members to their Conversazione.

To the President of Queen's College, for his obliging invitation to the Institution to hold the present Meeting in the College, and for the facilities so kindly afforded for the occasion.

To the Belfast Harbour Commissioners, for their invitation to inspect the Harbour, and for their hospitality in connection therewith.

To the Proprietors of the numerous Engineering, Shipbuilding, and Manufacturing Works, and other Establishments, visited by the Members, for their kindness in opening their Works during the Meeting.

To the Directors of the Belfast and Northern Counties Railway, the Great Northern Railway, the Belfast and County Down Railway, and the Larne and Stranraer Steamship Joint Committee, for their liberal invitations, comprising the privileges of special free transit for enhancing the convenience and enjoyment of the Members in the Excursions.

To the Reception Committee—especially to the Chairman Mr. Walter H. Wilson, to the Honorary Secretaries Mr. Bowman Malcolm and Mr. A. Basil Wilson, and to their active co-adjutors of the Executive Committee—for the attractive programme they have prepared for the Meeting and Excursions, and for the admirable and hospitable arrangements they have made for the convenience and enjoyment of the Members.

In connection with the second vote of thanks, the PRESIDENT drew attention to the awning which had been stretched across the greater part of the Examination Hall at a considerable distance below the roof. As the loftiness of the roof, while enhancing the noble proportions of the Hall and favouring its ventilation, had been found not conducive to its acoustic qualities, this remedy had been recommended and arranged by the kindness of the Professor of Engineering, Professor Maurice F. FitzGerald; and having proved so successful for the purpose, the Council desired to ask the College to accept the awning from the Institution, with a view to its usefulness on future similar occasions.

Sir EDWARD H. CARBUTT, Bart., Past-President, was sure that after such a gratifying Meeting the Members would wish to pass a hearty vote of thanks to the President, for the way in which he had conducted the Meeting and brought it to a successful conclusion.

The PRESIDENT, in acknowledging the vote of thanks, said it had been a great pleasure to himself to preside over a Meeting which had been so enjoyable from every possible point of view.

The Meeting then terminated at One o'clock. The attendance was 213 Members and 88 Visitors.

FLAX SCUTCHING AND FLAX HACKLING MACHINERY.

By Mr. JOHN HORNER, of Belfast.

Preliminary Operations.—Flax after being pulled up by the roots undergoes a retting process, by being placed in still water until fermentation sets in, and until the gummy matter has been removed which joins the boon or woody part to the fibre encircling it. It is then spread out in thin layers on short grass, and after a time is ready for the scutch mill, where the boon is removed and the fibre prepared for the market.

Scutching.—In introducing the subject of Flax Scutching as carried on in this country, and in giving an explanation of the machinery in use for this purpose, nothing novel can be described. This important branch of flax manipulation has not been directed by scientific skill; in many parts the hand process still survives. For breaking the boon, the stalks in small parcels are beaten with a mallet; and for clearing the flax of the broken boon, the workman with his left hand holds the flax over the stock, while with his right hand he strikes or threshes the flax with the scutcher. This process is precisely the same as that carried out in Egypt some three or four thousand years ago. In scutch mills, mechanical methods are employed; and the following account, taken from the British Encyclopedia of 1806, of the operations in use forty years prior to that date will serve as a description of the processes at present in vogue in most of the Irish scutch mills. "A water mill was invented about forty years ago, which with some late improvements makes great despatch, and in skilful and careful hands gives satisfaction. It has been generally constructed to break the boon by three dented rollers, placed one above the other, the middle one of which being forced quickly round takes the other two along with it; and one end of the handfuls of the flax being by the workmen directed in between the upper and middle rollers, the flax is immediately drawn in by the rollers; a curved board or plate of tin behind the rollers directs the flax to return again between the middle and undermost rollers; and thus the operation is repeated till the boon be sufficiently broke. Great weights of timber or stone at the ends of levers press the upper and under rollers towards the middle one. The scutching is next carried on by the mill in the following manner. Four arms project from a perpendicular axle, a box around the axle incloses these projecting scutchers, and this box is divided among the workmen, each having sufficient room to stand and handle his flax, which through slits in the upper part and sides of the box they hold in to the stroke of the scutchers; which moving round horizontally strike the flax across or at right angles, and so thresh out or clean it of boon. The horizontal stroke of the scutchers was long thought too severe and wasteful of the flax; and to obviate this objection an imitation of hand scutching has been applied to water. The scutchers then project from an horizontal axle, and move like the arms of a check reel, striking the flax neither across nor perpendicularly down, but sloping in upon the parcel, exactly as the flax is struck by the hand scutcher. This sloping stroke is got by raising the scutching stock some inches higher than the centre of the axle; and by raising or lowering the stock over which the flax is held, or screwing it nearer or farther from the scutchers, the workman can temper or humour the stroke almost as he pleases."

It will hardly be imagined by mechanical engineers that the above process of flax breaking and scutching, in use before Watt invented the steam engine, is so perfect as to be incapable of improvement; nor will it be supposed that an age so prolific in mechanical invention has not attempted the production of better means. That the system is far from perfect is evident from the fact that quantities of valuable fibre suitable for spinning are either wholly lost, or by re-scutching are in part restored, but only to be spun into the coarsest yarns. Machine makers and others interested in flax culture and flax spinning have from time to time devised methods tending to deal more gently with the fibre; but in this country at least no encouragement has been given them. It is obvious that, in order to gain a distinct advantage in flax breaking and scutching, the principle must be adopted which underlies the preparation of the same fibre for spinning, namely of treating it in small pieces and at slow speeds. The methods actually in use in breaking and scutching embody the opposite principle; in fact, as already stated in the foregoing quotation from the description given in 1806 of the breaking machine, it "makes great despatch"; and those who are entrusted with the preparation of the flax for the market prefer this great despatch to a slower and certainly more efficient means of working. When it is considered that the fibre of tho flax plant encircles the boon, and that the object of the scutching process is to get rid of the boon, it is clear that the greatest possible care should be taken in manipulation, in order not to injure the fibre which has to be dealt with before the boon that it encircles is reached. For this purpose long series of fluted rollers have been made, beginning with coarser and ending with finer teeth, and sometimes having a reciprocating motion; the top rollers run in vertical slotted bearings with springs or levers attached, allowing the rollers to rise, and so to accommodate the large bulk of flax-straw introduced. But even these were made with a view to quantity rather than quality of work; and as a consequence in the rolled material the boon is found in a condition more bruised than broken, and the work of its removal is carried out by subjecting it in an unprepared condition to the unyielding action of the scutching handle, which thus carries to waste a large amount of valuable fibre. Some time ago the writer made a set of bottomless rollers or skeleton drums, as shown in Fig. 7, Plate 56, in which the grooves have no bottom for the teeth to bruise the boon against; the set comprised some eight or ten pairs, running in fixed bearings, beginning open and gradually getting closer in pitch. Their action was to crack the boon thoroughly, without the slightest injury to the fibre; the rollers being bottomless prevented any rubbing, and the action was one of cracking, not crushing; from the construction of the rollers too the material was held loosely between them, and no undue strain was felt when it was gripped by the finer flutes. It was found that the greater quantity of the boon was separated, and fell beneath the machine; while the remainder was so thoroughly broken that a light scutching handle and little labour sufficed to remove it. Having fixed rollers, the machine would not allow of more than a certain quantity of material passing; and consequently the manipulation was considered too expensive, although the actual results were vastly superior.

That the flax-scutching industry of this country should be in such a backward condition is scarcely to be wondered at, when it is considered in whose hands it is. The farmer, whose interest it should be to get the largest yield of fibre from his growth of flax, is callous of such a result, and insensible to any advantages in scutching save those of expedition and cheapness. The scutcher has therefore no encouragement to improve; and if he had, his power capacity, generally water, curtails him, and he is naturally unwilling to lessen his output under existing arrangements.

Hackling.—The flax is now prepared for the threefold process of hackling:—roughing, machine-hackling, and sorting. The first and last are hand operations, and depend, the latter especially, on the skill and judgment of the operators.

Roughing is carried out as follows. The flax is divided into pieces or handfuls, each weighing from one-seventh to one-fifth of a pound according to quality. These are drawn through a coarse hackle or "rougher's tool," till the fibres are arranged parallel and uniform in length. The flax is then passed to the hackling machine.

Hackling Machine.—According to the quality of the flax and the degree of fineness to which it is to be hackled or cut, these machines vary from six to twenty hackles or tools in length, and from twenty to thirty hackles in the circumference of the leather bands or sheets which carry them. As shown in Plates 51, 52, and 53, which represent a machine having ten hackles in length, the various parts of the machine are supported on frame ends bound together by iron rails. A couple of bottom shafts AA communicate motion, by means of broad leather bands S called "sheets," to two top shafts BB set 24 inches higher on the frame. On the inner circumference of these sheets, as shown in Plate 54, cast-iron teeth are fastened by means of screws passing through holes in the sheets, and kept in position by iron plates on the outer circumference, which act as washers. The iron teeth have a couple of supports cast on, upon which, and resting on the outer circumference of the sheets, longitudinal angle-bars are screwed; these bars run the length of the machine, and on them are fastened the hackles, shown separately in Plate 57. On the bottom shafts are pulleys with teeth, and on the top shafts sockets with teeth, both corresponding in pitch with the teeth on the sheets; the bottom and top shafts are by these means geared together, and the corresponding sheet of hackles is geared in a similar manner. The hackles on one sheet are placed in alternating order in relation to those on the other sheet; and by means of wheels on the ends of the bottom shafts they are driven at the same speed in opposite directions. Change wheels are provided to vary the speed as desired. Suspended above the hackles by a pair of leather straps fastened to a pair of segments M, and counterbalanced by weights W, is a longitudinal trough or channel C, along which move the holders H, each having two of the roughed pieces of flax screwed into it. This channel receives an up and down motion from a lever arrangement L, Plate 55, actuated by runners on the faces of two wheels gearing into each other, and conveyed by connecting-rods to the segment. The speed of this motion can be varied by means of change pinions; and the dwell or rest of the channel when at its lowest point can be altered by means of hinges I on the lever L. Working in the channel is a long bar called the catch bar F, having fingers or catches attached corresponding in number with the holders in the channel, and having a to and fro longitudinal motion conveyed from a cam wheel, which acts through two levers V. The machine being put in motion, and the various wheels and levers taking up their work, the sheets and hackles revolve towards each other; the channel in which are the holders of flax moves the flax down and up again, thus subjecting it to the action of the revolving hackles; and when it has attained its highest point, the catch bar comes into play, and shifts the holder of flax to the next or finer hackle, and so on, till the flax has passed through the entire machine, and has thus had one half of its length hackled. It is then quickly changed to another holder, in which it is gripped this time by the hackled portion; and it is passed in a similar manner through another machine, which hackles the other half of its length, and the process of "machining" the flax is thereby completed. As one holder of flax is shifted by the catch bar to receive the action of finer hackles, another takes its place; thus the machine is hackling at any one time as many holders of flax as there are hackles in its length.

Removal of Tow.—The operation of hackling produces a quantity of tow or short fibres, which varies according to the strength of the flax and to the fineness of the hackles to which it is subjected. This tow remains attached to the hackles, and must be removed from each individual hackle at a certain point in its revolution. There are two modes of doing this, either by means of stripper rods, or by means of brushes and doffers. The former is by far the simpler mode, and in its operation makes the better tow; but it is limited in its utility to coarser machines, while finer machines require the more elaborate system of brushes and doffers.

Stripper Rods.—The stripper rods are laths of wood, shown in Fig. 8, Plate 56, about 3 feet long, 2¼ inches broad and ¼ inch thick, varying however in length according as they are intended to strip three or four hackles. They are shod at the ends with iron plates, which work in radial slots in the sheet pulleys AA. When in the revolution of the pulleys any individual slot attains a certain angle of inclination, the rod falls outwards by gravity, sweeping before it the tow accumulated on the hackles; and in its onward course, coming into contact with a concave guide G, it is pushed back again into its former position in readiness for another similar operation. The tow when removed from the hackle falls either upon a shaker of wire netting, which frees it from dust or particles of boon; or else upon a grating, through which these waste matters fall.

Brushes and Doffers.—The brush and doffer arrangement is more complicated and more expensive, but is necessary in machines having hackles of such a fine pitch that the action of the stripper rods will not free them from the tow. A cylindrical roller R, Plate 54, revolves beneath the hackles, having six or eight brushes mounted lengthwise on its circumference; these brushes pitch with the hackles, and are driven at a proportionate speed, which is necessarily much quicker. The brush removes the accumulated tow from the hackles, and deposits it on a doffer running slowly in the opposite direction. The doffer is mounted with pins set in the form of hooks; and these retain the tow, until acted upon by a doffer knife of steel with finely cut teeth, which, moving up and down, detaches the tow from the pins, and allows it to drop into a receptacle beneath.

Flax is as variable in quality as can well be imagined, being sold as high as £200 per ton for Courtrai and as low as £16 for poor Russian. Hackling machines therefore must naturally be varied to suit. For all classes of Russian flax, and for the lower qualities of Irish and other flaxes, stripper-rod machines are to be preferred. These flaxes being free from gummy matter, and the pitch of the hackles required being not too fine, the stripper rods are quite adequate to free the hackles from tow. Occasionally however a gummy flax of a coarse nature has to be treated, of which the gummy matter, sticking to the hackles, prevents proper stripping. To obviate this difficulty and to remove the gum, an ingenious brush arrangement has been introduced. Each set of hackles undergoes the action of a revolving brush U, Plate 59, of which the surface speed at one period is quicker than that of the hackles; the brush thereby frees the leading or cutting side of the pins from gum and from any accumulations of fibre. By a clutch and by either of the two arrangements indicated in Plates 59 and 60, the speed of the brush is at intervals reduced below that of the hackles, so that the hackle pins then revolving at a greater speed than the brush pass through the brush bristles, which thus clean the rear side of the pins, and re-deposit any fibre on the pins, whence it readily finds its way to the tow.

Stripper-rod machines are made single and duplex. If single they are worked in pairs, one machine hackling the root half and the other the top half of the handfuls of flax. Duplex machines, Plate 60, are two single machines united in one, for the mechanical arrangements of stripper-rod machines permit of their being thus united without detriment or crowding; moreover many of the parts, which in two separate machines are necessarily duplicated, can in duplex machines be combined. Besides being cheaper, duplex machines have other advantages: they require about half the space, and absorb but half the power; the counterpoise of the single machine is dispensed with, one channel balancing the other. The attendants too are closer to their work, and not having to pass from one machine to the other can devote more time to the careful spreading and screwing of the flax.

Brush and Doffer machines are made single, Plates 52 and 53. Their many working parts need more room to be spread out in, and being of a complicated nature, and requiring frequent inspection, those in the centre of the machine could not be got at if it were made duplex. For hackling the finer and middle qualities of flax, brush and doffer machines are undoubtedly preferable; from pins that are the most closely set, the tow can with ease be stripped when hackling the most gummy material; and the attendant can readily get about the machines, to set and adjust their various parts.

Hackles.—From the foregoing account of the relative merits of the two classes of hackling machines, it will readily be understood that the most important consideration in preparing a design for a machine is that of the hackles, specimens of which are shown half full size in Plate 57. In regard to these, many points have to be observed, such as number of hackles in length, number of hackles in circumference, length of hackles, pitch of hackles, number of pins per inch, length of pins, size of wire for pins, number of rows of pins, and manner of grouping.

The number of hackles in the length of a machine is dependent on the quality of the flax to be worked. Machines are at present made, varying from six to twenty tools or hackles; but no reasons exist, save those of expense and room, for want of extension in this respect. Machines with the lower number of tools are usually made for the lower sorts of flax, and more tools are added in proportion to the finer quality. By increasing the length of a machine and consequently the number of its tools, the difference in the degree of fineness of each tool is lessened; and thus the hackling is carried out more gradually, with greater care, and with less tow. No absolutely fixed rule can be followed in determining the number of tools that a machine should have; in this, as in all matters connected with flax hackling, discretion alone can be the guide. But it may be said generally that the number of tools should so increase in proportion to the fineness of the hackles as to maintain an equally gradual increase throughout.

The number of hackles in the circumference determines the pitch of the bars; and it is generally accepted that close-pitched hackle-bars are injurious alike to yield of flax and to tow. A certain amount of freedom should be given to the fibres; and it has been found in practice that close-pitched hackle-bars bind the flax too much, and do not give sufficient room for the tow of each hackle to remain separate. Tow is readily made nappy, if care be not taken in its removal.

Length of hackles depends on the class of the flax. By increasing the length, other things being equal, the number of tools is diminished. Thus where quantity of production is more to be desired than good quality of yield, the hackles may be made 14 or 15 inches long, and the holders being of equal length will accommodate more flax. This may be desirable when dealing with low qualities of flax, from which the dressed line and tow may be of relatively slight value; but in treating the better qualities of flax, hackles of from 10 to 11 inches length are quite long enough. The advantage to be gained by getting more hackles in the same length of machine is obvious; and a machine of twelve tools with 10-inch holders is preferable to a machine of equal length having 12-inch holders and only ten tools.

The number of pins per inch is regulated according to the fineness to which the flax is to be cut. On this point it is difficult to give any satisfactory information. Flax varies so much in quality that scarcely two machines are made alike in this respect. Although machines may finish with the same number of pins per inch, giving about the same degree of cutting, yet the other hackles must be arranged with due regard to strength, cleanness, hardness, pliability, thickness of roots, naps, character of the previous roughing process, and a number of other considerations. That a certain quality of flax is to be spun to a certain count of yarn cannot therefore be taken as an exact guide.

The length of the pins is dependent to some extent on the bulk of the flax, as some flaxes lie closer than others of equal weight. The pins vary in length from 1 to 1¼ inch over all, and their working lengths standing out of the hackle stocks are from 9-16ths to 13-16ths of an inch. It has been found in practice that the longer pins give the better yield; the flax not being so tightly bound, but allowed more freedom, is dealt with in a less rigid manner. On the other hand a shorter pin will give a better sort, that is to say a better hackled fibre, capable of being spun to a higher count of yarn. This is attributed to the fact that, in the finer hackles, the shorter pins, having less leverage, do not spring away from their work, but remain steady, penetrating the flax thoroughly. The friction of the closer-set hackle-stocks also gives a certain degree of what is called quality to the fibre. Recent improvements in hackling machines have gone in the direction of combining the advantages of long and short pins. It is evident that the flax is more bulky before being hackled than after, and that its bulk decreases in proportion to the tow taken from it in the process of hackling. Consequently if pins are made suitable for the flax as it enters the machine, and are gradually reduced in length as the flax is reduced in bulk, the twofold advantage of long and short pins is attained. In order to effect this object, and at the same time to keep the pins in line at the points, and to avoid a multiplicity of pin lengths, the hackle stocks are gradually thickened, and the effective length of the pins is thereby altered.

The thickness of the wire for the pins is in accordance with the degree of fineness of the hackle. A rule might be laid down for determining a certain size of wire for a hackle of so many pins per inch; but this rule would be varied so often, when the strength of the fibre is taken into account and the consequent strength of pin to resist the breaking strain, that discretion again must be used. Care must however be taken that the minimum space left between the holes is compatible with strength.

The number of rows of pins is fast undergoing a change. At one time it was thought impossible to get sufficient cutting power without two rows of pins, and in some cases even three. Practice shows that a single row of pins in comparison with a double row will cut in the proportion of fifty to seventy; that is to say, fifty pins per inch in a single row will cut equally as well as thirty-five per inch in a double row, although the latter has seventy pins per inch in its two rows: so that an increase in the fineness of hackles will, in the case of single rows, give all the cutting power wanted. Machines too are now made much longer than formerly, and the increase in the number of tools gives greatly increased cutting power. A decided advantage of single rows over double rows when hackling gummy material is that the pins are more thoroughly cleaned; for when two rows are employed, the cleaning brush in its action sweeps the hindmost pin clean, but leaves the leading or cutting pin clogged to some extent with gummy matter.

Grouping of pins is a point of much importance, but is too often neglected. It is clear that in coarse hackles, say one inch apart, if all the pins in each hackle of the round were set in exactly the same position, there would remain bands of the fibre one inch in breadth which would be absolutely unhackled. It is to obviate this that a system of grouping the pins is employed, as illustrated in Plate 58. Supposing a hackle 10 inches long be fitted with ten pins, or one pin per inch, and there be twenty-five hackles in the round or circumference of the sheet: hackle No. 1 is pierced for its first pin at a distance from the end compatible with strength, hackle No. 2 is bored 1–25th of an inch farther from the end, No. 3 the same distance farther still, and so on, till hackle No. 25 has its first pin one inch farther removed from the end than that of the first hackle. This grouping being carried out over the entire length of the hackle, it will be seen that no part of the flax is left unoperated upon. In this way hackles should be grouped up to ten pins per inch, above which, owing to fineness, grouping becomes unnecessary.

Speeds have next to be considered. Channels and hackles can be speeded independently of each other, by which means the quantity of work turned off and its hackled state can be regulated. The degrees of hackling depend largely on the number of pins passing through the flax in a given time. Thus an extra revolution or two given to the sheets in relation to the vertical movement of the channels will produce increased cutting, and is a simple and ready method of attaining the object, but one which cannot be generally recommended, because any increase in speed must result in decrease of yield. If a parcel of flax require more cutting, and it be not practicable to alter the hackles to finer, it would be wiser to reduce somewhat the relative speed of the channels, and thus give the flax a longer time in the hackles. A slow-running sheet with finer hackles is greatly to be preferred to a quick-running sheet with coarser hackles; by the former method the same number of pins may be passed through the flax, accomplishing the same degree of cutting, but with a much superior result. A recent improvement added to long hackling machines, with a supporting gable in the centre, enables a differential motion to be given to the hackles. The various shafts are separated at the centre gable, and driven from their opposite ends through change-wheels which drive them at different speeds. Thus the first half of the machine may be driven more quickly or more slowly than the second, so as to suit the exigencies of any parcel of flax that is being worked.

The size of the stricks or pieces of flax is also a matter of consideration. The smaller they are made, the smaller is the number of fibres to be dealt with; and as a consequence the hackle pins are capable of dealing with the strick more carefully and thoroughly than if a larger bulk be delivered to them. These advantages of slow speeds and small pieces do not require emphasizing, having been sufficiently taught by experience.

Ending Machine.—Naps appear frequently in the top end of some flaxes, and their thorough removal is a necessity. If the machine cannot free them, then the sorter must. Finer hackles will indeed grip them; but as they appear only in the extremities of the flax, unnecessary and destructive hackling would be given to the entire fibre, if these finer hackles were mounted on the machine. To obviate this, an adjunct machine has been introduced, called an ending machine, Plate 61, in which the speed of the hackles is not prescribed by that of the machine to which it is attached, though driven from the latter. The ending machine is quickly adjustable in height, and can thus be brought to operate on only that portion of the flax requiring its use. The hackles may be made as fine as necessary, and they effectually detach the naps without useless hackling of the fibres. When mounted with suitable hackles and driven at proper speed, these ending machines are equally useful in clearing out and switching the bulky roots of many flaxes, thus giving an equally hackled strick, without any detriment to the less bulky portions of the fibre which have already been sufficiently hackled.

The flax having been machined is taken to the sorter, who passes each handful through hackles proportionate to the fineness of the flax, thereby removing any lumps, naps, or loose tow left by the machines. He then squares the ends, and carefully sorts each piece into different qualities suitable for spinning. The hackling process is thus completed, and the flax, in this condition called "dressed line," is conveyed to the store.

Discussion.

Mr. Horner exhibited a series of samples of flax in the successive stages of its treatment, from the plant itself to the "dressed line" ready for spinning into yarn. Also a pair of bottomless rollers for cracking the boon without bruising the fibre; specimens of

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"rougher's tools" or coarse hackles for roughing the flax by hand; leather bands or "sheets" from the hackling machine, with successive lengths of hackles attached; separate specimens of hackles of different kinds; flax holder; and catch bar for shifting the flax holders to the next finer hackles.

Mr. MONTSERRAT H. WALKER, Castle Gardens Spinning Mills, Newtownards, said that flax was certainly treated a great deal better on the continent than it was in this country, and a greater proportion of yield was there obtained from the retted straw. The reason was in part the existence on the continent of a class of persons called flax farmers, who did not themselves grow the flax, but bought it on the field in a green state, and then pulled it up and worked it in their own interest with the object of getting the greatest possible yield out of it. In Ireland the flax grower merely wished to get it scutched, and to get it done as cheaply as possible, not caring whether there was much or little waste. All over Ireland the price paid by the flax grower for scutching was only about thirteen pence per stone of 14 lbs.; on the continent the process cost the person who bought the flax and scutched it himself about double that amount, and he nevertheless found that it paid him, because he got a greater yield out of the straw. The flax coming off the straw would give from 8 to 23 per cent. of scutched fibre, according to how the straw was handled and watered. There was also on the continent a much more uniform class of straw. The flax farmers there understood how to treat the fibre. In this country, where so much linen was produced, he thought it was a great pity that the industry of flax growing was not properly looked after. It would certainly be to the interest of flax mill owners if they would take into their own hands the treating of the flax after it was ready for pulling. At the present time his father was interested in a few fields of flax which he had bought, and he intended to try the continental system of treating it.

Mr. JOHN ERSKINE, Whitehouse Spinning Mills, had given much attention during his whole life both to flax and to engineering; and while confirming the accuracy of the descriptions given by the author in dealing so exhaustively with all the various stages of flax handling and hackling, he thought the march of progress had been slower than it ought to be in regard to all the improvements mentioned in the paper. Flax scutching still remained in a rude primitive state, and there was much yet to be desired in the handling of flax, though no doubt great efforts had been made to grapple with the subject. In the manipulation of the flax for the preparation of the "dressed line" great improvements had been made of late years in the manner described in the paper, especially in the grouping and the manner of using the pins in the hackles so as to be suitable to the particular class of material under treatment; and these improvements had enabled the mill owners to spin a more perfect yarn than formerly. The improvement arising from longer hackling machines, which had been referred to in page 291 of the paper, had consisted not only in improving greatly the fineness of the dressed line and in making less tow, but also in giving a more uniform character to the flax as regarded the size of the individual fibres. Unless these were made uniform in their thickness or fineness, it was impossible to spin a uniform yarn. The production of flax yarn was beset with much more difficulty than the production of cotton yarn; it was a kind of mechanical joining, and there was nothing in the flax fibre causing it to adhere as the fibres of cotton did. In the first place it was difficult in the hackling to produce the fibre evenly, and in the next place the doubling of the sliver was also a difficult process; and all this had to be successfully accomplished for producing an even yarn. Some of the Belfast manufacturers had devoted their lives to the study of the best mode of achieving this object; with the result that the flax produced by means of the longer hackling machines which had been introduced was second to none in the world. Flax spinners however had been a little too slow in recognising the fact that, notwithstanding all drawbacks, including the advance of wages from time to time, machinery of different kinds was now by the use of good tools being produced 50 per cent. cheaper than before. If flax spinners were equally on the alert to take advantage of existing good tools and to encourage the production of still better, they might

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do a great deal more than they had done in the way of rendering the manipulation of flax more perfect and reducing the expense of labour. Possibly their hesitancy might be partly owing to the unwillingness of operatives to handle a new machine; but at the present day, when labour was so uncertain, and when the artizan was at times unreasonable in his demands, he thought that flax spinners, considering the desirability of keeping in the front rank, ought to show a little more spirit in adopting improvements in scutching and various other operations in connection with the manipulation of flax.

Mr. JOHN B. PIRRIE, Barn Flax Spinning Mills, Carrickfergus, said his own experience confirmed the remarks of the previous speakers as to the need of improvement in the dressing of flax for the manufacture of yarn.

Mr. JOHN FISHER, Prospect Spinning Mills, having been connected with flax dressing from 1850, considered the paper had given a clear exposition of the present method of flax dressing; and in regard to scutching he agreed with the author that this process was still in a very primitive condition. It was true that attempts had been made to improve the method of scutching; but he believed it was the general opinion that these attempts had hitherto failed, and that there was still room for inventive genius to secure the wealth now going to waste in scutching. For the process of dressing the flax after it had been scutched, successive steps had been taken in the direction of improving the hackling machines. When he first went into the flax industry, there was in operation a contrivance called a flat machine, which was an attempt to perform by machinery the work previously performed with hackles by hand. The flax was stretched, not vertically as in the present machines, but horizontally; the hackles travelling horizontally passed through it and hackled the under side first; then the business of the boy in attendance was to turn the flax over on the hackles, so that the upper side might be done. That was but a small improvement upon hand-hackling. Then there came the reversing-cylinder machine, invented by the late James Combe of Belfast, in which an attempt was made to do away with the boy turning the flax over on the hackles. The flax was suspended from an iron holder, which was placed longitudinally over the centre line of a horizontal cylinder carrying the hackles; as the cylinder revolved in one direction it dressed the side of the flax next it, and then by automatically reversing its motion it dressed the other side. The machine was cumbrous, expensive to keep up, and unsatisfactory. Instead of the horizontal plan an upright method was then adopted, which was the most sensible and likely to be the most lasting mode of dressing flax, as represented in the machines that were now made. The flax was suspended vertically, and the two sides of the piece were dressed simultaneously by the hackles. In that way the operation was performed as perfectly he thought as it could be expected to be done by machines. There used formerly to be no more than six hackles in the length of the machine; but as stated in the paper there were now as many as twenty in some of the machines. These longer machines were decidedly preferable in many ways to the shorter: they could be run at a lower speed, which was a decided advantage; greater wear could be got out of them, they lasted a far longer time, and gave much better results in the cutting of the flax more evenly. They were of course more expensive than the shorter machines; but this was compensated for by the improved results. Of the ending machine he had not been able to avail himself much, preferring to have the hackling completed in the long machines, which he generally managed to accomplish. But no doubt there were cases in which the ending machine was useful; and some spinners found advantage in it.

Mr. WILLIAM DRONSFIELD asked whether it was not necessary to keep the points of the hackle pins sharp and true; and if so, what method was adopted for accomplishing that object.

Mr. BENJAMIN A. DOBSON, Member of Council, noticed that the backward condition of the flax-scutching industry in Ireland was

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attributed in the paper to the fact that the farmer did not seem to take much interest in getting the fullest yield of fibre from his flax. A similar state of things existed in the much larger industry of cotton manufacture. The yearly value of the flax crop in the north of Ireland he did not know; but the cotton crop in the southern states of America was worth annually between 75 and 100 millions sterling, and, extraordinary as it might appear, that industry was in the same backward condition as the flax industry; for every year that enormous crop of cotton was damaged to the extent of 5 per cent. of its value by inefficient machinery. This had been pointed out to the cotton producers, both the planters and the ginners, and the fact was acknowledged by them; but because it was nobody's interest in particular to take the matter in hand and improve the present condition of things, it was left as it was. The cotton planters took their cotton to be ginned; and all that they wanted was to get it ginned as soon as possible, and to sell it for what they could get for it. It commanded a ready sale, and they never had it left on their hands: so that they were satisfied. With regard to the ginners, who owned the machines that separated the cotton-seed from the fibre, their only object was to get through the work as quickly as possible, and at the least cost of time, trouble, and money. So it was that these two parties, whose one object ought to be to get the best possible result out of the abundance which nature had provided for them, yet neglected their duty to such an extent that there was annually a loss of considerably over three millions sterling in the produce of the cotton plantations in the southern states of America.

Mr. Bryan Donkin, Member of Council, asked for some information as to the power required for working the machines described in the paper, and the speed at which they were driven; and also the approximate number of machines at work in this country and elsewhere.

Mr. Horner was glad to have had the present opportunity of preparing a paper for the Institution upon this subject, in order that one of the real Irish grievances might be thoroughly and properly ventilated. The scutching of flax in this country he considered was carried on in a manner which was seriously to be deplored; and many thousands of pounds sterling were annually going to waste, which might go into the pockets of the farmers. Among the samples of flax which he had brought for illustrating the successive stages of its treatment were some of the plants freshly pulled yesterday, having still the flower on part of them; and for these the present time of holding the meeting was most opportune, as the flax was just now being pulled. It was pulled by the roots, and after being steeped for some time in water for allowing the necessary chemical change to take place, it was dried and produced in the condition shown by another sample. The boon which was inside the fibre was then taken out. It was made brittle by the steeping or retting process, so that it readily fell away from the fibre when properly treated. Proper rolling was necessary, in order that the boon might be removed without unnecessary loss of fibre. Mr. Walker, who, besides being a practical flax-spinner, was a practical scutcher, was quite right in saying that on the continent flax was treated in a much more sensible manner than in Ireland. Here the farmer insisted on having his flax scutched at once, in order that he might get his money; and was callous as to the yield. Accordingly a large bulk was put through the old-fashioned rollers, the invention of 150 years ago, and about 25 per cent. of the fibre was lost in the tow. On this point he had been informed by Mr. Walker that the loss ranged from 15 to 40 per cent., and that 25 per cent. might be taken as the average; and that with proper treatment fully two-thirds of this might be retained in the long fibre. When it was considered that the average price of the tow when re-scutched was about £14 or £15 per ton, which might be in fibre at £50 per ton, it would be seen that there was a great loss to the farmer. He exhibited a piece of flax which had been rolled by the old rollers; it would be seen that it was scarcely broken, and that it would stand perfectly upright; it was simply softened, so that the scutcher was enabled to bend it better to the action of the scutching handle. The boon was inside the fibre; and in order to get the straw

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away from the boon, the fibre had to be treated first, and a great waste was thereby occasioned. On the principle of the bottomless rollers and of the flax being treated in smaller pieces, it was thoroughly broken; there was practically very little straw left, and what was left was readily taken away. The mode of dealing with flax in scutching mills should be to treat it in small pieces, working it carefully. Into this flax-growing and flax-spinning country a far larger amount of flax was imported than was grown here, although it was possible for Ireland to grow the whole of the flax required for home consumption. After the flax had been scutched, as shown by the samples exhibited, it was received by the mills for hackling, and was there first roughed; then the ends were squared, and the flax was hackled in the machines. The samples of machined flax showed how the fibres were split and cut longitudinally into thinner sizes. It was then drawn through the smaller and finer tools, by means of which it was carefully sorted into the various spinning qualities. These were the principal processes which the flax went through from its grown state until it was completely hackled.

The support which Mr. Walker and Mr. Erskine had given in their remarks was of great value, as coming from those who were so intimately acquainted with the flax trade. Mr. Fisher's historical sketch of the progress of flax hackling within his own recollection was also most interesting.

It was certainly desirable that the hackle pins should be kept sharp and true (page 299); but there was no method of sharpening them after they had been fixed in the hackles, as could be done in the preparation of other fibres. If a pin became blunt, it had to be replaced by another.

It was a surprise to him to hear (page 300) that the industry of preparing cotton for the cotton mills in America was as much behind-hand as the flax-scutching industry. Things were therefore perhaps not so much behind-hand in Ireland, in relation to other countries, as he had himself imagined.

The driving power required (page 300) was from $\frac{1}{2}$ to $\frac{3}{4}$ H.P. for driving one of the hackling machines, according to the length of the machine. In regard to the number of machines working in this country, roughly speaking there was one pair of hackling machines to about a thousand spindles; and in Ireland there were probably 600,000 or 700,000 spindles.

The PRESIDENT proposed a hearty vote of thanks to Mr. Horner for his interesting and instructive paper, of which the Members had already shown their appreciation by their applause.

ELECTRIC LIGHTING IN BELFAST.

By Mr. VICTOR A. H. McCOWEN,
Electrical Engineer to the Belfast Corporation.

Belfast, like many other large cities, was slow to make advances towards the adoption of a system of Electricity Supply; the Corporation prudently preferring that others should experiment, and that they themselves should profit by the experience thus gained. As moreover they were the owners of the gas works, and justly proud of the reputation they had gained of having their thoroughfares well lighted by gas, and as that undertaking was also a paying concern, they had no intention of allowing private enterprise to occupy the field. No fewer than seven private notices were served in 1882 of intention to apply for provisional orders for power to supply electricity within the city. All these applications were successfully opposed; the Corporation remained in possession, and for seven years no further active steps were taken.

During these seven years the output of gas had risen from 615 million cubic feet in 1882 to 907 million cubic feet in 1889; and absolute necessity was shown for the extension of the gas works to cope with the enormously increased consumption. A great difficulty arose as to where a suitable site for that extension could be found. The Gas Committee were thus led to consider the introduction of Electric Lighting. In September 1889 they reported that in their opinion the time had arrived when the Corporation should obtain powers to supply electricity for lighting, &c., within the city; and they also recommended that authority should be given to apply to the Board of Trade for a provisional order for this purpose. Application was duly made, and the necessary power was granted in the Belfast Electric Lighting Order 1890 and in the Belfast Corporation Various Powers Act 1890. The Gas Committee were authorised to pay £50,000 out of the surplus profits of the gas undertaking towards the establishment of the electric light. Mr. James Stelfox, engineer and manager of the gas works, reported regarding the proposed extensions, that "it must remain with the Gas Committee to decide to what extent they would anticipate the success of the electric, or any other method of lighting, resulting in a decrease in the demand for gas. * * * * I believe that as yet the use of electricity in any place has never resulted in a lessened demand for gas, and I see no reason to believe that such a result is now probable." The Gas Committee subsequently reported to the Council that they had had under consideration the introduction of lighting by electricity, and that, taking into account the importance of the matter, they recommended the Council to appoint a special committee to procure all the information requisite for their guidance thereon, and to draw up a report embodying the same. This committee was appointed, and, after visiting the principal electrical installations in and around London and the Electrical Exhibition at the Crystal Palace, reported in October 1892 in favour of establishing an installation of 10,000 lamps of 8 candle-power, with room for extension. It was next decided to obtain the assistance of a consulting engineer, and Professor Alexander B. W. Kennedy, F.R.S., of London, was appointed. On account of the saving in capital cost, and other circumstances of the case, he recommended the system about to be described.

Area supplied.—The area at present supplied with electricity in Belfast is shown in the plan, Plate 62, and comprises probably the best part of the city. It includes first-class shops and offices, hotels, clubs, theatres, and churches; and in Howard Street and College Square private houses. The following statement gives the percentage of lamps connected for different classes of consumers:—

	Per cent.	Per cent.
Shops, closing late	8	
„ „ early	30	
„ „ „ but late on Saturday night	25	
	—	63·0
Offices		11·0
Hotels and Clubs		6·0
Theatres		12·0
Churches		4·8
Private Houses		2·0
Motors		1·2
Total		100·0

As shops and offices together form 74 per cent. of the total consumption, the shape of the load curves depends greatly on their hours of closing. In Fig. 20, Plate 73, are given curves for Wednesday and Saturday in the same week, the ordinates denoting ampères at 110 volts. The Saturday curve shows the effect of the late closing of some shops, a much better load being then given, with no very objectionable peak. The distance of the farthest lamp from the station is as yet only about 800 yards, since the present area supplied with electricity is only a small part of the city. When mains are laid in the residential districts, the load curve will doubtless be greatly improved. A good motor day-load is looked forward to in course of time, as there is no doubt respecting the several advantages of electric motors, more especially to small users of power, and where the power is required intermittently. Up to the present the question of street lighting has not been considered.

Mode of Distribution.—The system of distribution is what is known as the three-wire low-tension. The current is supplied to consumers at 110 or 220 volts pressure. The distributing mains laid throughout the area, as indicated by the distinctive lines in Plate 62, are connected up in a network, and fed by feeders from the generating station at the seven points shown. The feeders deliver the current at the feeding points of the distributing mains at a pressure of 220 volts. The drop in the feeders at full load is 10 per cent. The pressure between the middle wire and the positive or negative is 110 volts. Pilot wires are connected from the feeding points to voltmeters in the generating station: so that the switchboard attendant can always see what the pressure is at these points, and keep it constant by due regulation.

Charges and Pressures.—The charge for current for lighting is 7*d.* per Board of Trade unit, with discount ranging from 2½ to 17½ per cent. according to consumption; the maximum discount reduces the price to 5·77*d.* per unit. The charge for current for motors, heating, &c., in daylight hours, is 4*d.* per unit with the above discounts, of which the maximum reduces the price to 3·3*d.* per unit. Meter rents range upwards from 2*s.* 6*d.* per quarter, according to size of meter. The meters in use are those of the Ferranti type. Installations containing over fifty lamps of 8 candle-power are wired either with single 220-volt lamps, or with pairs of 110-volt lamps in series, or on the three-wire system. Motors of over one horse-power are supplied with current at 220 volts.

Station.—The generating station is situated between Chapel Lane and Marquis Street, Plate 62, within 250 yards of Castle Place, which is practically the centre of the city; it is therefore a good position from which to distribute the supply. In the selection of the site, the question of convenience for delivery of coal, removal of refuse, &c., had not to be considered. The buildings were designed by Mr. C. Stanley Peach, of London; their general arrangement and the position of the machinery &c. are shown in Figs. 2 to 4, Plate 63. The shape of the site is rather irregular, and the space available has been made use of to the best advantage.

The engine room occupies the central and larger portion of the site, and measures 85 feet long by 33 feet wide at the east end and 44 feet at the west end. A 6-ton overhead travelling crane is provided, of which all the motions are actuated from below by means of ropes. The switchboard platform is raised about 4 feet above the floor level, and runs the whole length of the west wall of the engine room. The battery room, measuring 28 feet square, is situated between the engine room and the offices, on the same level; it contains four rows of stands for the cells, and is provided with ample means of ventilation. The offices occupy the west end of the site, with frontage to Marquis Street. The meter-testing room and store room are above the offices, on the first floor. A fitting shop and driver's room are placed at the east end of the building; and above them is the cooling tank, Fig. 4, measuring $34\frac{1}{2}$ by $12\frac{1}{2}$ feet and 4 ft. 2 ins. deep. Owing to the absence of anything like solid foundations to build upon, the whole site was piled with 480 piles of 35 feet length. A 3-inch memel flooring was secured to the pile heads, and on this was placed concrete to a depth varying from 3 to 4 feet, to form the engine beds and the foundation for the walls of the building.

Engine Room.—The machinery in the engine room consists of the following engines and dynamos. Four 120 I.H.P. tandem double-acting horizontal gas engines, running at 160 revolutions per minute, and driving, through eight $\frac{7}{8}$-inch diameter cotton ropes, four 57·6 kilo-watt dynamos of 240 ampères and 240 volts at a speed of 600 revolutions per minute. Two 60 I.H.P. single-cylinder double-acting horizontal gas engines, running at 160 revolutions per minute, and driving through eight $\frac{3}{4}$-inch diameter cotton ropes two 26·4 kilo-watt dynamos at 750 revolutions per minute. Two 150 I.H.P. four-cylinder single-acting high-speed vertical gas engines, running at 380 revolutions per minute, coupled direct to two 72 kilo-watt dynamos of 300 ampères and 240 volts.

Switchboard.—The switchboard, of which a front elevation is shown in Fig. 6, Plate 64, consists of five slates, each about 7 feet high; the centre one is 36 inches wide, and the others 32 inches. All are bolted to an iron frame-work, fixed on the switchboard platform about 4 feet from the engine-room wall. The centre slate carries the feeder and omnibus-bar voltmeters, the battery instruments and regulating gear, and the middle-wire ammeter and connections. The other four slates carry the feeder and dynamo instruments, switches, &c.; the two on the left-hand are for the positive side of the system, and the two on the right-hand for the negative side.

In Plates 65 and 66 are shown diagrams of the switchboard and connections to the machines, battery, hospital-cell board, &c. The machine and feeder bars, which are the vertical bars on the outer slates, are fixed on the front; and each is provided with three holes, through which a plug can be inserted to make connection with any one of the three omnibus bars that are fixed horizontally at the back of the board, as shown dotted in Plate 64. The feeder bars are those connected to the ammeters F, to the switches FS, and to the fuses FF. From the feeder-fuses to the point where they leave the station, the feeders are brought in the form of bare solid copper rods supported on insulators, which are fixed behind the match-boarding at the south side of the engine room. The machine bars are side by side with the feeder bars, and the connections to the machine ammeters and automatic switches are at the back. The leads from the dynamos consist of insulated cables, which are brought along behind the match-boarding at the north side of the building.

The automatic switches are arranged to break circuit, should the current from the machine fall below 10 ampères. The shunt change-over switch is shown above the automatic, and connected with it by an interlocking lever. An ampère-hour meter is connected in the circuit of each dynamo, and registers the work done during a run, the readings being taken at start and finish. The voltmeters are Kelvin multi-cellular electro-static, and are provided with multiple-contact switches. The feeder voltmeters show the pressure at any feeding point between the middle wire and the positive and negative wires. The bar voltmeters show the pressure between the positive and negative omnibus bars, and also between the middle wire and any of the omnibus bars. The dynamo voltmeters are used for showing the voltage of the machines before putting them on to the circuit.

The batteries are connected through their ampère-hour meters, polarized ampère meters, and emergency switches, to the top omnibus bars. The usual practice at full load is to have all the machines and feeders plugged in parallel on this bar; but should it be necessary to run any particular pair of feeders at a different voltage, this can be done by plugging that pair of feeders and a machine on the bottom omnibus bar. As a matter of fact it has never been required to run a separate machine on a separate pair of feeders, as a very even drop all round is obtained.

The link connections shown at L, Plates 65 and 66, are in the circuits of the small machines, and are used for connecting them in the following different ways:—(*a*) as balancing machines on either side of the system; (*b*) as a special charging circuit for the batteries; (*c*) in parallel with the large machines across the system. The starting resistances and the shunt resistances are fixed in the cellar beneath the switchboard. The shunt regulating switches are fixed on the handrail of the switchboard.

Battery.—The battery consists of 126 cells of the Electric Power Storage Co.'s 34 K or heavy-discharge type: 63 cells for the positive side of the system, and 63 cells for the negative. The capacity of each cell is 500 ampère-hours, at a discharge rate of 100 ampères; the battery will however give a much higher rate of discharge for short periods. The plates are contained in lead boxes, which are supported on wooden stands, being insulated from the latter by means of glass oil-insulators. There are also eight hospital cells, which can either be used for assisting weak cells, or be put in series with the main battery. The connections from the battery to the regulator and switchboard consist of bare copper rods supported by oil insulators suspended from the roof.

The method of regulating the battery is different from that usually practised of cutting in or cutting out end cells. The regulation here is accomplished by putting the cells at the middle-wire end of the positive battery in parallel with those at the middle-wire end of the negative battery: the other ends of the batteries being connected through ammeters and emergency switches to their respective omnibus bars. The regulator is placed in the battery room, and is worked from a handwheel on the switchboard by means of a rack and pinion. A reversible ampère-hour meter, which registers both charge and discharge, is connected in each battery circuit.

Dynamos.—The dynamos are by Messrs. Siemens Brothers, double-pole with drum armature and shunt-wound. The rope-driven machines are provided with heavy fly-wheels, and the larger ones have three bearings. The two small machines of 26·4 kilowatts have double-wound armatures, each winding connected to a separate commutator. By means of a plug-board the armatures can be put in series or in parallel, so that the machines can be run at 110 to 120 volts for balancing, or at 220 to 240 volts across the system. The voltage can also be increased to 270, if required. The rope-driven machines are placed close up to the back end of the back cylinder, to save floor space; and backward driving has been adopted, in order to get the slack of the ropes at top.

Gas Engines.—The six horizontal gas engines were manufactured by Messrs. Dick, Kerr and Co., Kilmarnock, under Hartley and Kerr's system. As shown in Plate 67 the four larger are double-cylinder double-acting, with the cylinders working tandem and the two pistons on the same rod, which is connected through cross-head and connecting-rod to the crank. The bore of the back cylinder is 13¾ inches, and of the front 13½ inches; the stroke is 20 inches. The fly-wheel and driving-wheel, one fixed on each end of the crank-shaft, are each 8 feet 5 inches diameter, and weigh 37 cwts. and 29 cwts. respectively; the driving-wheel is grooved for eight ⅞-inch ropes. These engines run at a speed of 160 revolutions per minute, and indicate 120 H.P.; the number of explosions per minute is 320, or two per revolution.

The two smaller engines are single-cylinder double-acting; the cylinder is 13½ inches diameter and 20 inches stroke. They run at 160 revolutions per minute, and indicate 60 H.P. The number of explosions per minute is 160, or one per revolution. The fly-wheel and driving-wheel are each 7 feet diameter, and each weighs 57 cwts.

The cyclical variation in the speed of the tandem engines is very small, owing to the number of explosions, their low initial pressure, and their even distribution, the number of explosions being as 4 to 1 in comparison with a single-cylinder single-acting engine. The impulses occur in the following order:—

1st	impulse	in the	Front	cylinder,	Front	end,	angle of crank	0° to 180°
2nd	,,	,,	,,	,,	Back	,,	,,	180° to 360°
3rd	,,	,,	Back	,,	Front	,,	,,	360° to 540°
4th	,,	,,	,,	,,	Back	,,	,,	540° to 720°

There are thus four complete Otto cycles in two revolutions; and this working is continued right through the whole range of the engine load. The diagram in Plate 74 illustrates the impulses, and shows at a glance the relative steadiness in comparison with the single-acting Otto-cycle gas engine in general use. Each impulse is marked, and each half revolution of the crank is represented by a vertical line.

Governing.—The method ot governing is different from that usually adopted of missing an explosion. With these engines the impulses are continuous, and are graduated according to the load in the manner about to be explained. In Plate 75 are shown sets of indicator diagrams taken from No. 6 tandem engine, at several different loads, from 20 per cent. overload down to only dynamo excited, all ends working right through, and no explosions being missed. [See also Table 1 in page 324.] In Plate 74 are shown the relative positions of the different operations which are being performed in the cylinders, and how evenly the work is divided, an Otto cycle being completed during each single stroke. In the single-cylinder engines the same even distribution of work done is not obtained; and heavier fly-wheels have therefore been provided.

With the tandem engines it is at once seen that very steady working may be attained without running at a high speed. These engines were originally intended to work down to one-third of full load without missing an explosion; and it was thought that at lighter loads an explosion might be missed, and still sufficient steadiness be maintained. In Fig. 25, Plate 76, is shown a diagram taken when running at light loads and missing an explosion. It was found however that the missing of an explosion at light loads affected the steadiness too much; and the adjustment of the engines was then taken in hand under the immediate personal supervision of

Mr. Hartley, with the result of obtaining finely graduated impulses, such as the writer believes have previously been unknown in gas engines. The engines are now capable of working from 20 per cent. overload down to no load, without missing an explosion. The diagrams in Fig. 26, Plate 76, show the engine running light and without cutting out. Here the initial pressure is 60 lbs. per square inch; the pressure when the piston is at half stroke is 20 lbs.; and the terminal pressure is 3 lbs. The word explosion seems here somewhat misapplied, considering the extremely low steady pressure all through the stroke.

Graduation of Explosions.—The difficulty to be overcome was the prompt ignition of the charge without initial shock, and under the difficult conditions of a rich charge varying down to an extremely poor one; and also to reduce the terminal pressure by more complete combustion in the cylinder. The diagrams in Fig. 27, Plate 76, show the graduated nature of the explosions under varying loads after the final adjustment of the engines. It will be noted that the charge ignites promptly and without shock; and the low terminal pressure shows that the charge is also utilised to the best advantage.

The quantity of air supplied to the cylinder is practically constant, the quantity of gas only is varied; and hence the difficulty of ignition. It is well known that a poor mixture of gas and air ignites slowly; this is shown in the diagrams in Fig. 25, Plate 76. The method adopted, whereby the results shown in the diagrams in Figs. 26 and 27 were obtained, appears to indicate that stratification actually takes place in the gas-engine cylinder, and that for certain purposes it may be rendered of great use. The regularity of the ignition was attained by admitting gas to the cylinder later and later in the charging stroke; and even at full power a considerable quantity of air is drawn into the cylinder before gas is admitted. At light loads this results in the cylinder being almost full of air immediately following the piston, with only a small portion of rich and explosive mixture near the ignition chest. The ignition is controlled by a timing valve, which opens always at the same point of the stroke.

The gas charge is varied by a novel device, which is controlled by the governor. The gas valve is worked by an expanding cam, which may be described as an ordinary gas cam divided into three leaves in planes at right angles to the axis of the cam shaft. These three leaves are capable of being spread or closed by a sliding key, which slides in a keyway cut in the cam shaft, and is controlled by the governor. A helix upon the key engages the leading leaf of the cam; and when the key is moved longitudinally along the shaft in either direction by the governor, the cam is spread or closed as the case may be. The middle leaf is loose on the shaft, and has a slot in which works a pin fixed on the leading leaf; the third leaf is fixed on the shaft. The key and cam are held in position by a detent, during the opening of the gas valve; but immediately it is fully opened the detent is released, leaving the cam again under the control of the governor. A Buss governor is employed, and the gas-valves are gridiron slide-valves; all other valves are of the mushroom type.

Ignition.—The method of ignition is by hot tubes, which are of ordinary wrought-iron, nickel steel, or porcelain. The economical life of the wrought-iron tubes is found to be rather short; after about fifteen hours the tube gets partially choked up, and gives late firing.

Lubrication and Packing.—The cylinders are provided with valve lubricators opening inwards; the oil is drawn in during the charging stroke. Asbestos packing is used for the piston-rod glands, and no trouble has occurred with hot rods, notwithstanding the high temperatures to which they are exposed; they are as bright and clean as those of a well-kept steam-engine. The lubricant is ordinary gas-engine oil.

Cooling Water.—The cooling water from the overhead tank, Fig. 4, Plate 63, is circulated by means of small centrifugal pumps driven by belt from the crank-shaft of each engine. The evaporation is made up through a ball-cock valve connected with the tank, and supplied by the town water supply. The town water can also be mixed in any required proportion with the tank-water. Separate connections are made to the cylinder covers and jackets; and regulating cocks are supplied for the necessary adjustments. When returned to the tank, the water is discharged into a long timber shoot provided with a number of holes, by which it is broken up into a shower, thus presenting a larger surface to the atmosphere, whereby the cooling is accelerated. This plan has been found of distinct advantage; and on few occasions has water been required from the town supply, even when running four or five engines together. The capacity of the tank is 10,700 gallons at 4 feet depth.

Gas Supply.—The gas is supplied through an 8-inch branch from the Corporation gas mains, brought into the station at the Chapel Lane end and connected to three 500-light dry meters; the three are connected in parallel, and each is provided with a by-pass. The gas is conveyed from the meters through an 8-inch main, which runs the whole length of the engine-room, supported by brackets on the columns. Each engine gets its supply from the main through a 3-inch branch pipe, provided with a valve and gas bag. The ignition gas is supplied through a separate pipe and meters. The horizontal engines each deliver their exhaust gases through 6-inch branch pipes into a common 18-inch exhaust main. A silencer is connected between the main and the uptake. In Figs. 30 and 31, Plate 78, are shown curves of gas consumption, plotted from the results of tests on a tandem and on a single engine: they show the total gas consumption per hour, per indicated H.P. per hour, per electrical H.P. per hour, and per kilo-watt per hour; and also the percentage of efficiency, or ratio of electrical H.P. to indicated H.P. These results are also given in Tables 1 and 2, pages 324–5.

High-Speed Engines. — The high-speed vertical engines, Plates 68–70, manufactured by the Acme Gas Engine Co., Glasgow, have four single-acting cylinders arranged in two lines of two in tandem, working upon opposite cranks. The pistons in the bottom cylinders form guides in the usual manner. The piston-rod, connecting the top and bottom pistons, passes through a water-jacketed cylinder, the packing being ordinary Ramsbottom rings on the rod. The gas valves and mixture valves are of the mushroom type, actuated by means of cams. The piston valves, which control the exhaust and time the ignition, are worked from a small crank-shaft, fixed on the same level and parallel to the main crank-shaft, being geared from it in the ratio 1 to 2 through steel spur-wheel and pinion. The cam shaft is also worked from this, through an upright shaft gearing with both.

These engines being closed in, the base forms an oil chamber, in which the crank-shaft works. The bottom pistons and the bottom piston-valves are lubricated by the splash from the cranks. Lubricators are provided for the top cylinders only. The engine base is extended to take the dynamo, and the crank-shaft is coupled direct to the armature shaft. A fly-wheel of 3 feet diameter is fixed on each end of the crank-shaft, the one at the dynamo end weighing 28½ cwts. and the other 24½ cwts. Each cylinder is fitted with a stop valve, so that the engine can be run on one or more cylinders as desired. Each cylinder is provided with an ordinary pendulum governor; and the usual method of governing, by missing an explosion, is employed. Ignition is obtained by means of the hot tube. When the engine is running at full load, at its normal speed of 380 revolutions per minute and no explosions missed, 190 impulses per minute are obtained in each cylinder, or a total of 760 per minute in the engine. This, aided by the heavy fly-wheels, gives very steady running.

The engines are provided with a separate silencer and exhaust pipe for each line of cylinders. The cooling arrangements are practically the same as in the horizontal engine. Tank water is circulated by means of a centrifugal pump; and there is also a direct connection from the town water-mains. Cooling pipes are also fitted to the crank chamber. This kind of engine is specially suited for steady driving, high speed being attained without knocking, because all parts are kept in constant thrust by having a high compression of about 90 lbs. per square inch in one or other of the cylinders at every upstroke. When the bottom right cylinder is exhausting, the top right is compressing, and vice versâ. The same operation occurs in the left line of cylinders; and by cushioning at the top of the piston-valve cylinder, the piston valves are also kept in constant thrust. Where economy of floor space is a consideration, this kind of engine is highly suitable. An engine of 150 I.H.P. requires a floor area of 6½ feet by 5 feet, or 32½ square feet over fly-wheels; and the combination of engine with dynamo of 72 kilo-watts necessitates an area of only 62½ square feet.

Starting Arrangements.—The engines can be started either electrically or by compressed air. In the electrical starting the dynamo is run as a motor off the omnibus bars, pulling the engine round until it begins to explode. First the machine is plugged on to the omnibus bar, the machine automatic switch being left open. A starting resistance is then plugged into the machine circuit, the resistance switch being on the off contact. The field of the machine is next excited from the omnibus bar, by closing the shunt switch on the top or bar contact, Plates 65 and 66. An initial start is given to the engine by the driver, and the current is switched on gradually through the starting resistance. As soon as the dynamo is up to speed, the starting current is cut off. The voltage is then regulated by the shunt resistance, and the dynamo switched on to the circuit by closing the automatic switch. The closing of this switch actuates the shunt switch, changing it over from the top to the bottom contact, and the dynamo then runs as a shunt machine. The electrical starting is worked from the switchboard by the engineer in charge.

In starting by compressed air, the engine has first to be turned by hand by the driver into the correct starting position. The stop valve admitting the compressed air is then opened, and is again closed as soon as a few explosions have taken place. The dynamo is then run up to speed and its voltage regulated; and it is put on to the circuit in the ordinary way.

Compressed-air Starting Apparatus.—The air compressor has two water-jacketed single-acting cylinders of 4½ inches diameter and 8 inches stroke. The pistons are driven by opposite cranks. The admission and delivery of air are regulated by slide-valves moved mechanically. The crank-shaft carries on one end a fly-wheel, and on the other a mortice wheel, which gears with a steel pinion on the motor shaft. The power is supplied by a 6 H.P. electric motor, running at 800 revolutions per minute, and taking its current from the mains at 220 volts pressure. The air receiver is 12 feet long by 4 feet diameter, made for a working pressure of 100 lbs. per square inch, and tested up to 200 lbs.; it is provided with safety-valve, pressure gauge, &c. A 4-inch air main from the receiver runs the whole length of the engine room, with a 2-inch branch pipe to each engine.

In the tandem engines the connection is made to the back end of the back cylinder. The compressed air is admitted during the impulse stroke of that end by a valve actuated by a cam, thus giving an impulse every second revolution. The gas is cut off from the back cylinder while starting. As soon as an explosion occurs in the front cylinder, the compressed air is shut off, the starting cam put out of action, and the gas turned on, letting the back cylinder take up its part of the work.

In the single-cylinder double-acting engines the arrangement is the same, with only the difference in working that the gas is admitted to the front end of the cylinder, while starting, but not to the back end.

In the high-speed four-cylinder engines the compressed-air connection is made to the bottom right-hand cylinder, which for starting purposes is specially provided, firstly with a valve to close the mixture-admission port, secondly with an exhaust passage and a valve to close it, and thirdly with an inlet for the compressed air. The valve of this inlet is worked by a double-throw cam, thus giving an impulse for every revolution in this cylinder. The speed increases quickly; and as soon as the explosions take place in the other cylinders, the compressed air is shut off, the starting cam thrown out of action, and the gas turned on to this cylinder.

Mains, Feeders, and Distributers.—These are mostly bare copper strip in concrete culverts. The strip is simply supported on earthenware insulators placed 6 feet apart, which are held in place by a pitch setting. The strip is laid in before the cover flags are put down; and extra copper can be drawn in at any time without raising the flags. Everywhere the culvert is placed beneath the footway. The lengths average 25 yards, and are built with a fall towards the junction boxes, in order to allow any water that may get in to drain off. The average depth of the copper below the surface is 20 inches. The space required for a three-way culvert for a distributing main is 27 inches wide, with a minimum depth of 18 inches below the surface. For a five-way culvert, which takes the distributing mains and a pair of feeders, the space required is 34 inches wide with a depth of 18 inches.

Culverts.—In Plate 71 are shown sections of three-way and five-way culverts. These are built of cement concrete in the proportion of five of gravel and broken stones to one of Portland cement. The side walls are 6 inches thick, and the bottom 4 inches, all faced inside with cement. The covering slabs are 2-inch Kilrush or Caithness flags. The culvert when dry is itself a fair insulator, which is a great advantage where there is a possibility of sometimes getting a sag of the strip between the insulators, as may occur through the carelessness of workmen. At street crossings, and under narrow footways where there is no room for a culvert, insulated cables in cast-iron pipes are used. Connections between the lengths of strip, or between cable and strip, are made in the street boxes by means of gun-metal grip-boxes, which clamp the ends together.

The copper strip is 1 inch wide and 0·2 inch thick, giving 0·2 square inch section. This is the section used in all the distributing mains, both for middle and outer wires. When the lamp density—that is, the number of lamps per yard—increases, the section of the outer wires can be increased by putting in another strip on the top of the present. The section of the feeders varies from 0·4 to 0·8 square inch, according to the length; the longest feeder at present is 520 yards.

The distributing mains are all in parallel, and are connected at as many points as possible in order to equalise the pressure. They are brought back to the station to supply current for the lighting, &c. The middle wire is brought back from four different points of the network. The pilot wires are in the form of three separately insulated conductors, twisted together and cased in lead; some have paper insulation and others impregnated jute. The joints are protected, either by a lead sleeve soldered to the lead covering and filled with insulating oil, or by being placed in a special joint-box, which is filled with insulating material run in hot. The pilot wires are drawn into cast-iron pipes laid along one side of the culvert.

On account of the wet nature of the ground and the comparatively low level of the city, special precautions had to be taken against water getting into the culverts or accumulating in them; and the aim has been to make the whole water-tight. The street boxes are built of brick, faced inside with cement, and the bottoms are concreted. They are provided with a cast-iron frame and cover, the latter being filled with concrete. A water-tight joint is made between cover and frame by the use of House's slow-setting cement. Junction-boxes placed in the roadway are provided with specially heavy frames and covers, the latter being filled in with wood blocks. The covers are provided with inspection plugs, which allow of making a rapid examination of the system without lifting the covers. Any accumulation of water can be removed through the inspection-plug hole by means of a small hand-pump. A record is kept of the condition of the boxes, and of the dates of their having been pumped out. The covers are also lifted periodically for the ventilation of the culverts. No trouble has been experienced from gas accumulating in the culverts. At the laying of the mains all defective gas services were renewed; and those that ran close to the culvert were coated with a mixture of pitch and tar.

The service mains are rubber-covered cables drawn into wrought-iron pipes, which are laid from the nearest street-box. They are connected to the Corporation-main fuses immediately inside the building. The connections to the distributing mains are clamped in the case of bare copper strip; and insulated T joints are employed for connecting to cable.

Throughout the system the positive and negative mains occupy fixed relative positions under the footway; namely, the negative main or feeder is everywhere next the kerb, and the positive next the houses. In the street boxes, Plate 71, the positives P are coloured blue, the negatives N red, and the middle wire M black; the service cables are coloured in the same way. The feeders and distributers are shown in their respective positions in the plan, Plate 62.

General Remarks.—From the experience here gained, the author is of opinion that a gas-engine station necessitates more attention than a steam-driven station; and more drivers of a better class are required for a given power than in the latter station. A couple of men are always required for the electrical starting of an engine; without their help the strain on the armature would be too great, if the current were switched on when the machine was standing.

The following statement shows the cost of current sold from 23rd January to 31st December 1895:—

Number of units sold	82,771
„ lamps connected (equivalent in 8 candle-power)	10,500
Revenue from sale of current	£2,186
Average price obtained per unit	6·34*d.*

	Cost of production.			Per unit sold.
	£	*s.*	*d.*	*Pence.*
Gas used as fuel	501	3	0	1·450
Oil, waste, water, and stores, including ignition tubes	80	4	3	0·233
Salaries and wages at generating station	444	17	4	1·290
Repairs and maintenance of buildings, engines, dynamos, and accumulators	93	16	8	0·272
Repairs and maintenance of mains	76	4	6	0·221
Rents, rates, and taxes	236	0	0	0·684
Management expenses, &c.	413	9	11	1·200
Insurance	23	2	0	0·067
Total and Average	£1,868	17	8	5·417

A machine can be started up and got on circuit in about two minutes, the stand-by units being kept plugged-up on the switchboard and the ignition tubes kept hot. For the sake of efficiency the machines are run as near to full load as possible; but, as far as governing is concerned, they can be run at any part of their load. The cost of fuel (gas), per Board of Trade unit sold for the year ending 31 December 1895, worked out at 1·45*d.* This, with gas at 2*s.* 3*d.* per 1,000 cubic feet, is equivalent to 53·7 cubic feet per unit sold, or 46·7 feet per unit generated. The total efficiency, or ratio of units used to units generated, is 91 per cent. This is equal to an average consumption during the year of 34·8 cubic feet of gas per E.H.P. hour. A curve for the cost of gas per unit of electricity, generated and sold, throughout the year is shown in Plate 72, and it will be noticed that it varies but little, whatever the output may be. The cost of engine-room stores, including oil, waste, water, and ignition tubes, amounts to 0·233*d.* per unit sold, which compares favourably with steam-driven stations. Ignition tubes form a heavy item of the cost. Good results are now being obtained with porcelain tubes, which require only a short time to heat up. The cost of cooling water works out at a low figure, and this is due to the use of a tank of large capacity, which has special cooling arrangements.

In Plate 72 are shown curves for (*a*) number of 8 candle-power lamps connected with the main, (*b*) maximum number of 8 candle-power lamps alight at one time, and (*c*) Board of Trade units sold per week. By comparing curves *a* and *b* it will be seen that the number of lamps alight at one time has not been above 53 per cent. of the lamps connected. Curve *c* shows the great difference between the summer and winter output. June and December load curves are shown in Fig. 21, Plate 73, the ordinates denoting ampères at 110 volts.

The cables and copper strip were laid and jointed by the Corporation workmen. Messrs. M'Laughlin and Harvey of Belfast contracted for the buildings; and Messrs. Scott and Sillar of Aberdeen and Messrs. William Coates and Son, Belfast, for the roadwork. The cast-iron work was manufactured by Messrs. Maclaren and Messrs. Shaw and Co. of Glasgow; and the cables were supplied by

Henley's Telegraph Works Co., Silvertown, and by the Callender Bitumen, Telegraph and Waterproof Co., London. The copper strip was supplied by Messrs. Curtis of Dublin, and by the British Insulated Wire Co. Messrs. Dick Kerr, and Co. of Kilmarnock and the Acme Gas Engine Co. of Glasgow supplied the engines and dynamos. The compressed-air plant was made by Messrs. Kerr, Stuart and Co. of Stoke-upon-Trent. The Electrical Power Storage Co. furnished the battery, and Messrs. Holmes and Co. of Newcastle the switchboard. The station started to supply current on 23rd January 1895 with 2,300 lamps of 8 candle-power; there are now 13,500 lamps of 8 candle-power connected with the mains.

The following statement shows the quantity of units of electricity sold by meter to private consumers, and otherwise accounted for, and also the total quantity generated, from 23rd January 1895 to 31st December 1895 :—

		Units.
Quantity sold at 4*d.* per unit . . .	574	
,, ,, at 7*d.* per unit . . .	82,197	82,771
,, used on works	3,822	
,, lost in battery	6,304	10,126
,, accounted for		92,897
,, not accounted for		2,229
Total Units generated		95,126

Total efficiency = 91·0 per cent.
Loss in batteries = 6·7 ,, ,,
Loss in mains = 2·3 ,, ,,
100·0

The total maximum supply demanded was 159,000 watts, which is equivalent to 5,300 lamps of 30 watts each.

TABLE 1.—*Tests of No. 6 Tandem Double-cylinder Double-acting Horizontal Engine and Dynamo. Taken* 24 *April* 1896. *See Plate* 75, *and Fig.* 30, *Plate* 78.

Number of test			1	2	3	4	5	6
Duration of test		minutes	30	30	30	30	30	15
Load factor		per cent.	120·0	100·8	74·8	52·3	25·2	exciting
Mean Speed, revolutions per minute		revs.	166·5	167·5	168·0	166·0	168·0	167·0
Mean Ampères			285·7	241·5	179·4	125·2	60·2	—
Mean Volts			240·9	240·2	240·0	240·1	240·0	240·0
Mean Kilo-watts		Kw.	68·8	58·1	43·1	30·1	14·5	—
Mean Electric Horse-Power		E.H.P.	92·3	77·9	57·8	40·3	19·4	—
Mean Indicated Horse-Power		I.H.P.	120·5	101·4	80·2	64·4	45·0	—
Kilo-watt hours			34·4	29·0	21·5	15·0	7·2	—
Electric horse-power hours			46·1	39·0	28·9	20·1	9·7	—
Indicated horse-power hours			60·2	50·7	40·1	32·2	22·5	—
E.H.P. ÷ I.H.P.		per cent.	76·6	76·8	71·8	62·7	43·2	—
GAS USED, cubic feet per hour.								
Excluding ignition	Total		2,494	2,230	2,020	1,906	1,748	1,576
	per Kw.		36·3	38·5	46·5	63·7	120·5	—
	per E.H.P.		27·1	28·6	35·0	47·5	90·1	—
	per I.H.P.		20·7	22·0	25·2	29·6	38·8	—
Including ignition	Total		2,521	2,258	2,048	1,936	1,776	1,605
	per Kw.		36·6	39·0	47·6	64·3	122·6	—
	per E.H.P.		27·4	29·0	35·5	48·0	91·7	—
	per I.H.P.		20·9	22·3	25·6	30·1	39·2	—
Pressure of Gas		inch of water	1	1	7-8ths	1	1	1
WATER USED, lbs. per hour.	Total		21,830	13,100	22,560	12,720	12,750	22,600
	per Kw.		317	226	520	423	880	—
	per E.H.P.		237	168	391	314	657	—
	per I.H.P.		181	129	282	197	283	—
Temperature of Water	in cooling tank	Fahr.	85·5°	84·5°	84·0°	86°	83·5°	—
	leaving jackets	Fahr.	119·0°	108·4°	131·7°	106°	112·0°	95·5°

TABLE 2.—*Tests of No. 2 Single-cylinder Double-acting Horizontal Engine and Dynamo. Taken 5 and 6 June* 1896. *See Plate 77, and Fig.* 31, *Plate* 78.

Number of test			1	2	3	4	5	6	7
Duration of test		minutes	30	30	30	30	30	30	15
Load factor		per cent.	117·8	99·3	75·8	53·6	23·8	50·6	23·8
Mean Speed, revolutions per minute		revs.	160·3	162·0	160·5	163·0	160·0	161·0	163·0
Mean Ampères			214·8	183·0	138·8	96·3	44·3	55·0	43·8
Mean Volts			144·7	143·0	143·7	147·0	141·8	242·4	144·4
Mean Kilo-watts		Kw.	31·1	26·2	20·0	14·1	6·3	13·3	6·3
Mean Electric Horse-Power		E.H.P.	41·7	35·1	26·8	19·0	8·4	17·9	8·4
Mean Indicated Horse-Power		I.H.P.	57·6	48·8	43·1	33·2	23·8	29·8	22·3
Kilo-watt hours			15·5	13·1	10·0	7·1	3·1	6·7	1·6
Electric horse-power hours			20·8	17·5	13·4	9·5	4·2	8·9	2·1
Indicated horse-power hours			28·8	24·4	21·5	16·6	11·9	14·9	5·6
E.H.P. ÷ I.H.P.		per cent.	72·2	71·8	62·3	57·3	35·5	60·1	37·9
GAS USED, cubic feet per hour.									
Excluding ignition	Total		1,208	1,080	990	970	896	634	532
	per Kw.		38·9	41·2	49·5	68·5	142·0	47·5	84·5
	per E.H.P.		29·0	30·4	36·9	51·0	106·0	35·4	63·0
	per I.H.P.		21·0	22·1	23·0	29·2	37·6	21·3	23·9
Including ignition	Total		1,221	1,093	1,002	983	909	648	548
	per Kw.		39·4	41·8	50·1	69·4	144·0	48·5	87·0
	per E.H.P.		29·4	31·2	37·4	51·7	107·0	36·2	64·8
	per I.H.P.		21·2	22·4	23·3	29·6	38·2	21·7	24·5
WATER USED, lbs. per hour.	Total		—	—	3,610	3,880	—	3,880	—
	per Kw.		—	—	180	274	—	290	—
	per E.H.P.		—	—	134	204	—	217	—
	per I.H.P.		—	—	84	117	—	130	—

*

In tests 1 to 5 both ends of the cylinder were working, no explosions being missed.
In tests 6 and 7 one end only of the cylinder was working.

TABLE 3.

Tests of No. 7 Four-cylinder Single-acting High-speed Vertical Engine, coupled direct to dynamo.

Taken at Glasgow 29 *and* 30 *May* 1896. *See Plates* 68–70, *and Fig.* 32, *Plate* 79; *and page* 344.

Number of test		1	2	3	4	5	6	7	8	9	10	11	12	13
Duration of test	minutes	60	60	60	60	60	30	30	30	30	30	30	30	15
Load factor	per cent.	101	100	100·6	102	100	74·6	50·6	110	113	101	75·3	50·5	24·9
Mean Speed per minute	revs.	373·3	373·0	373·7	372·3	373·5	375·0	385·0	356·6	370·0	383·4	384·5	390·0	395·0
Mean Ampères		304·0	300·2	304·0	303·6	303·0	224·3	150·1	325·7	322·7	303·1	223·6	150·9	74·25
Mean Volts		240·0	240·5	238·4	240·4	237·8	240·0	242·3	243·7	251·9	240·6	242·5	241·3	240·5
Mean Kilo-watts	Kw.	72·96	72·20	72·40	73·40	72·08	53·73	36·40	79·30	81·30	72·86	54·20	36·40	17·90
Mean Electric H.P.	E.H.P.	97·7	97·0	97·1	98·5	96·7	72·1	48·8	106·2	109·0	97·6	72·7	48·8	24·0
Mean Indicated H.P.	I.H.P.	—	—	—	—	—	—	—	—	140·0	133·26	101·3	80·75	59·8
E.H.P. ÷ I.H.P.	per cent.	—	—	—	—	—	—	—	—	72·7	73·2	71·6	60·5	40·2
GAS USED, cubic feet per hour.														
Excluding ignition	Total	2650	2710	2670	2620	2643	2230	1880	2552	2626	2530	2080	1682	1280
	per Kw.	36·4	37·5	36·9	35·75	36·6	41·5	51·7	32·2	32·4	34·8	38·4	46·3	71·5
	per E.H.P.	27·1	27·9	27·5	26·6	27·3	31·0	38·5	24·0	24·05	25·9	28·6	34·5	53·3
	per I.H.P.	—	—	—	—	—	—	—	—	18·75	19·0	20·25	20·85	21·4
Including ignition	Total	2678	2738	2698	2648	2671	2258	1908	2580	2654	2558	2108	1710	1308
	per Kw.	36·8	37·9	37·3	36·2	37·0	42·0	52·5	32·6	32·7	35·2	39·0	47·0	73·2
	per E.H.P.	27·4	28·2	27·8	26·9	27·6	31·3	39·1	24·3	24·4	26·2	29·0	35·1	54·5
	per I.H.P.	—	—	—	—	—	—	—	—	18·95	19·2	20·8	21·2	21·9

TABLE 4.

Tests of No. 7 Four-cylinder Single-acting High-speed Vertical Engine, coupled direct to dynamo.

Taken at Belfast 4 *and* 5 *November* 1896. *See Plates* 68–70, *and Fig.* 33, *Plate* 79 ; *and page* 344.

Calorific value of Belfast gas at 60° Fahr. and at 14·7 lbs. pressure per square inch, 570 British thermal units per cubic foot.

Number of test		14	15	16	17
Duration of test	minutes	30	30	30	15
Load factor	per cent.	92	89	54	26·3
Mean Speed, revolutions per minute	revs.	—	410	410	405
Mean Ampères		282	274	153	79·4
Mean Volts		235	234	254	238·5
Mean Kilo-watts	Kw.	66·3	64·1	38·85	18·9
Mean Electric Horse-Power	E.H.P.	88·9	86·0	52·1	25·4
GAS USED, cubic feet per hour.					
Excluding ignition	Total	2690	2666	1832	1344
	per Kw.	40·6	41·6	47·2	71·2
	per E.H.P.	30·3	31·0	35·2	53·0
Including ignition	Total	2730	2702	1873	1387
	per Kw.	41·2	42·2	48·2	73·4
	per E.H.P.	30·7	31·4	36·0	54·6

TABLE 5.

Tests of No. 8 Four-cylinder Single-acting High-speed Vertical Engine, coupled direct to dynamo.

Taken at Glasgow 27 *and* 28 *March* 1896. *See Plates* 68–70, *and Fig.* 34, *Plate* 79; *and page* 344.

Calorific value of Glasgow gas at 60° Fahr. and at 14·7 lbs. pressure per square inch, 750 British thermal units per cubic foot.

Number of test	1	2	3	4	5	6	7	8	9	10	11	12
Duration of test . minutes	30	30	30	30	30	30	60	60	60	60	60	60
Load factor . . per cent.	excited	25·4	50	75	98·5	105·2	99·5	100	99·5	101·2	101·1	100
Mean Speed per min. revs.	365	360	355	352	353	350	375	390	395	395	395	395
Mean Ampères	—	76·2	150	225	298	325	299·5	298·5	297·6	300	301·6	300
Mean Volts	240	240	240	240	238	233·3	239	241·5	240·2	241·6	241·2	240
Mean Kilo-watts . . Kw.	—	18·3	36·0	54·0	70·9	75·77	71·64	72·0	71·5	72·5	72·7	72·0
Mean Electric H.P. E.H.P.	—	24·6	48·25	72·4	95·2	101·5	96·1	96·75	95·5	98·0	98·0	96·7
GAS USED, cubic feet per hour.												
Excluding ignition Total . . .	760	1290	1566	1900	2260	2320	2395	2375	2330	2352	2438	2432
Excluding ignition per Kw. . .	—	70·5	43·5	35·2	31·95	30·6	33·4	33·0	32·6	32·5	33·5	33·75
Excluding ignition per E.H.P. .	—	52·6	32·4	26·3	23·75	22·8	24·9	24·6	24·4	24·0	24·9	25·15
Including ignition Total . . .	788	1318	1594	1928	2288	2348	2423	2403	2358	2380	2466	2460
Including ignition per Kw. . .	—	72·0	44·3	35·75	32·3	31·0	33·8	33·4	33·0	32·9	33·9	34·1
Including ignition per E.H.P. .	—	53·6	33·0	26·65	24·05	23·15	25·2	24·9	24·7	24·3	25·2	25·4

Discussion.

Mr. E. R. DOLBY considered the electric lighting station in Belfast was one of the most interesting stations to an electrical engineer, seeing that there was so large a use of gas engines. From the plan of the station, Fig. 2, Plate 63, it would be noticed that each of the two high-speed vertical engines occupied, he thought, only about half the floor space of any one of the four larger horizontal gas engines. Seeing that each of the four latter would give off about 120 H.P. and each of the two vertical engines about 150 H.P., and that with the vertical engines there was thus about 300 H.P. upon only about a quarter of the floor space occupied by 480 H.P. with the horizontal engines, it would be interesting to learn how the capital cost of the two plans compared. In examining the results of the tests, it would be observed in Table 1 (page 324) that the gas used per E.H.P. hour in the larger horizontal engine was 27·1 cubic feet, or 27·4 cubic feet including ignition; and the engine was then giving off its full load of 120 I.H.P. From Table 2 (page 325) it appeared that the smaller horizontal engine, when giving off only 57·6 I.H.P., was using 29·0 cubic feet per E.H.P. hour, or 29·4 cubic feet including ignition. With these results it would be interesting to compare those of the high-speed vertical engines, as soon as the latter were ascertained.

One important point to which he thought attention should be given was the composition of the gas consumed in the engines. There was a considerable difference he believed between the gas in Glasgow and that in Belfast. It must therefore be an important matter in preparing for the employment of gas engines to know exactly what quality of gas was about to be used; otherwise tests made in the engine works with one kind of gas might appear to be satisfactory, and then, when the same engines came to be tested in the electric station with gas not of the same quality, results might be obtained which did not come up to the desired standard. It would be a valuable addition therefore to the paper if the analysis of the gas were given. It would also be interesting to note the amount of light which could be obtained from the gas by using it in ordinary

(Mr. E. R. Dolby.)

burners, and then how much more candle-power could be obtained by using it in gas engines for producing electric light. If this advantage were clearly shown to the consumers, it would be a great incentive to the use of electric lighting instead of gas, apart altogether from the question of damage done to decorations by gas lighting.

Mr. Bryan Donkin, Member of Council, enquired how many indicators were employed for taking the indicator diagrams from the two engines of which the tests were recorded in Tables 1 and 2 (pages 324–5); he presumed there were four, one at each end of each cylinder. The figures in Tables 1 and 2, and the diagrams, Figs. 30 and 31, Plate 78, showed clearly how the quantity of gas diminished per E.H.P. hour as the power increased; this was a result which had been checked by many other experiments.

He asked also whether any trouble had been experienced with the gas engines in regard to internal deposit; and how often they required to be cleaned. Instead of calculating the heating power of the gas from an analysis, he thought it would be better if the number of thermal units per cubic foot could be given by means of a gas calorimeter. What was the mechanical efficiency of these gas engines, both double and single-cylinder? that is, the difference between the indicated horse-power when running at full load and when running empty. And had any experiments been made, altering the quantity of circulating water in the jackets? Small centrifugal pumps were mentioned (page 314), which he supposed could be driven at different speeds according to the quantity of circulating water required for obtaining the maximum efficiency from the gas engines.

The interesting experiments described in the paper he observed were of only thirty minutes' duration, and two of only fifteen; and he enquired whether that was considered sufficient, or whether there might have been any alteration in the results if the trials had been considerably longer. The gas used as fuel, being supplied from the city gasworks, would of course be the ordinary illuminating gas; and he should like to know how much the cost would be reduced, if a cruder gas of poor illuminating power were used, such as Dowson gas. Ignition tubes being stated in page 322 to form a heavy item of the cost, he asked whether electric ignition had been tried.

Mr. Benjamin T. O'Brien asked what had been the reason for adopting gas engines instead of steam engines. It appeared to him that gas was a much more expensive means of generating power than steam. The gas engines seemed to work efficiently, the best result of the tests in Tables 1 and 2 (pages 324–5) being nearly as low as 20 cubic feet per I.H.P. per hour, which he supposed was a good economy for gas engines. Others of the tests showed a greater consumption of gas; and taking the price given in page 322 of 2*s.* 3*d.* per thousand cubic feet, the average cost would perhaps come to about two-thirds of a penny per I.H.P. per hour. The steam engine he thought would show far greater economy, with a consumption of say 2 lbs. of coal per I.H.P. per hour, making the cost with coal at 10*s.* a ton about one-ninth of a penny per I.H.P. per hour. Even if gas engines worked well at first, they grew wasteful he believed after working for a length of time.

Professor John Goodman considered the consumption of gas in the tests in Tables 1 and 2 (pages 324–5) was far too high, ranging as it did from 27 up to 107 cubic feet per E.H.P. per hour. At the Yorkshire College, Leeds, a gas engine of about 60 I.H.P. was working up to full power with less than 20 cubic feet of gas per E.H.P. per hour, and did not go above 36 cubic feet when working down to about half power. Taking a week's run with light loads and heavy loads, the consumption came out about 25 cubic feet of gas per E.H.P. per hour; and at the price of gas in Leeds the cost was about one halfpenny (0·51*d.*) per E.H.P. per hour, which was little more than half of the cost in the Belfast station. Considering that the gas engine at the Yorkshire College was a comparatively small one for private use only, he thought the result in Leeds was remarkably good in comparison with that in Belfast, and that there must be something radically wrong with the

(Professor John Goodman.)

Belfast engines to be using such a large amount of gas. Of course the latter engines, when making two explosions per revolution, or even only one, ran much more steadily for electric lighting than such an engine as that in Leeds, which had only one explosion in every two revolutions; nevertheless, by means of a heavy fly-wheel both at the engine and on the dynamo, almost perfectly steady running was obtained, and in regard to steadiness of light the lighting was now perfectly satisfactory, though it had not been so when first started. The gas engine would not have been put in, but for the fact that the college was cramped for room; and a steam engine with large boiler would also have entailed much higher capital cost.

The method of governing by graduating the gas supply he believed had been carried out for at least ten years; and it had been found an important improvement to arrange a gradual diminution of the gas, instead of missing explosions. The driving of the dynamo by ropes from a gas engine he thought was rather objectionable. As was well known, it was difficult to get the light sufficiently steady when a dynamo was driven by a tight belt from a gas engine. If however a slack belt were used, and a small fly-wheel were placed on the dynamo, slip occurred at every explosion, and the usual flicker was avoided. Thus a small amount of slip was highly desirable. With rope driving it was well known that there was not so much slip as there was with a belt. Hence he thought rope driving was not so suitable as belts for electric lighting. Certainly the belt he was using at Leeds was working remarkably well; it had been running there about three years, and had given no trouble whatever.

The starting arrangement at Belfast was certainly novel, and he thought it was an exceedingly good plan. It was always a difficult matter to start a big gas-engine. At Leeds there had not been much trouble, owing to the use of a Tangye self-starter, by means of which with the aid of two men the engine was generally able to be started on the first attempt. The self-starter consisted simply of a pump, by which the necessary supply of air and gas was pumped into the cylinder to the required pressure; it was then ignited, and in nineteen cases out of twenty it started the engine at once, without any trouble at all. [See also pages 342–4.]

Mr. Henry McLaren, as a member of the Engineering Committee of the Yorkshire College, had had a good deal to do with the gas engine in use there, and could confirm the statement made by Professor Goodman in regard to the economy of its working. One point about which he should like to enquire in the present instance was the question of nuisance to neighbours. The position of the Belfast station, right in the centre of the city, led him to ask whether complaints had not been made by the neighbours as to the noise arising from the running of the gas engines. Being also concerned with the manufacture of steam engines for central-station electric lighting, he was well aware that there was great difficulty in running even a steam-driven station in a city without giving rise to trouble, and often to expensive law-suits. The cost of gas for working, 1·45*d.* per unit sold (page 322), was certainly high; and he should naturally expect an electric station in Belfast to run for a third of that cost in coal consumption. The cost of stores was said to compare favourably with steam-driven stations; but 0·233*d.* per unit he thought was hardly a favourable result. With steam engines, such as were in use in Huddersfield and Oxford, the cost of the stores, oil, waste, &c., he believed was only 0·05*d.* per unit, which was a great reduction on Belfast. The question already asked, why the gas engines had been adopted here, was one that had occurred to himself also; and he should like to know whether in extending the station the use of gas engines would be continued, or whether steam would be reverted to. No doubt gas engines had made great strides, and could be well adapted for certain situations. Though it might be suggested that by using Dowson gas much better results would be obtained, yet he feared it would be found that the trouble caused by using impure gas, owing to the tar and residuals left in the engine and to the eating away of the exhaust valves, would detract greatly from its cheapness, and would result in a serious increase of expense.

Sir Edward H. Carbutt, Bart., Past-President, observing that in the Belfast station the foundations had been put upon piles planked over, with concrete placed on the top, asked whether any

(Sir Edward H. Carbutt, Bart.)

effect of the engines working had been felt in buildings some distance away. Did the vibration caused by the engines communicate itself through the water-bearing strata underneath to the houses of the neighbourhood? In the St. James's district in London, where a large electric station had been placed in the midst of the clubs, inconvenience had arisen because every now and then a vibration was set up when all the engines happened to be working in one direction. He enquired whether the same effect had been produced in Belfast; and, if so, whether anything had been done to neutralise the vibration.

Mr. John H. Greenhill thought the question why gas engines had been adopted in Belfast (page 331) had probably been asked from an economical point of view; and when it was taken into consideration that one of the ostensible reasons for the establishment of a central electric station in Belfast had been to relieve the gas works, this question became of double significance. Presumably the engineer advising the Corporation must have had good reason for recommending the adoption of gas engines; Mr. McCowen having been appointed subsequently was not responsible for the decision. It was probable that an extension would take place, and that steam engines would be adopted in future. With regard to the economy, or want of economy, of gas engines, and the statement that a certain amount of gas was consumed per hour per electrical horse-power and also per indicated horse-power, he thought it was highly desirable that the consumption should likewise be given per brake horse-power, because in the measurement of electrical horse-power a second element was introduced by the dynamo, which might to a certain extent interfere with the correct determination of the real efficiency of the gas engine as a motor. If the brake horse-power were always measured, it would be known at once exactly how much the engine was developing outside itself. Not being a gas-engine maker, he had had occasion to test a great many gas engines by different makers; and he considered the results obtained in the Belfast central station were not favourable, namely 20·9 cubic feet of gas per indicated horse-power per hour in such large engines. In his own experience engines of one-fourth the size had done better; with a small engine giving half the brake horse-power of these the consumption had been even less than 18½ cubic feet of Belfast gas per brake horse-power per hour. By the plan of gradually reducing the supply of gas by means of the governor, instead of cutting it off altogether, he thought it was well known that the gas consumption would be greatly increased. It was perhaps a steady way of governing the engine to graduate the gas consumption to a certain extent according to the power, but it was not an economical way, because the proper mixture of gas and air was not obtained; it was more economical to cut off the supply of gas altogether, and miss explosions; this he thought had been found out long ago by various gas-engine makers. An electric governor, as it was termed, had had to be abandoned because it was not economical; there was not a proper mixture of gas to give an efficient result. A mistake he thought was committed by gas-engine makers in depending too much on the candle-power of gas, as it might be of a high illuminating power, and yet contain a comparatively small number of thermal units.

Mr. J. Hartley Wicksteed, Vice-President, had had something to do, like Mr. McLaren, with the large gas-engine of 60 I.H.P. which had been erected at the Yorkshire College, Leeds, for the purpose of driving a dynamo for the electric lighting of the college. The first difficulty experienced with the engine was that it caused the gas in the houses in the neighbourhood to jump up and down, and sometimes to go out, owing to the large draughts of gas taken in intermittently by the engine, which worked on the Otto cycle, having one impulse in two revolutions. That was cured by means of india-rubber gas-bags and other devices for storing the gas. The next trouble was the noise and disturbance made by the sucking in of the air, when the engine took its great mouthful for the explosion. It made all the loose window sashes in the neighbourhood up and down the two adjoining streets rattle a great deal; every loose sash shook to and fro with the suction of the air, and the residents were much disturbed. That difficulty was overcome to a certain extent by putting straw into the areas of the inlet windows through which the

(Mr. J. Hartley Wicksteed.)

air entered; so that the air had to strain in through the straw, and could not enter in large waves. There was also a great deal of difficulty from the noise of the exhaust; and numerous notices were served upon the college by the neighbourhood to stop the nuisance, which was abated by inserting a long cylinder, filled with pebbles, to form a section of the exhaust pipe. Moreover the engine was in the cellar of a building, part of which was devoted to chemical laboratories, where often balances and other instruments were in use; and it would not do in any way to shake the building. A plan was adopted, which had been devised by Professor Goodman, who had previously had some experience in London of a small gas-engine placed in a workshop under a lithographers' workroom. The lithographers could not do with any vibration or jar, and they complained when the little gas-engine was started. The difficulty had been overcome by putting in strong mats of cocoa-nut fibre, like door mats, between the concrete foundation and the base of the engine. That plan was accordingly adopted at the Yorkshire College: there was a concrete foundation, upon which were laid mats of cocoa-nut fibre; a timber frame rested on the mats, above the timber were three or four more thicknesses of mats, then an iron plate, and upon this the engine. There were long holding-down bolts through the concrete, coming up through the base-plate of the engine. By that plan, instead of shaking the building, the engine shook itself only. The plan would have answered well, if the engine frame had been properly designed for such a foundation: that is, if it had been a plain base-plate, all flat on its underside, which would have lain fair over the whole of the mats, and so would have distributed the weight of the engine and the nipping pressure of the bolts over a large surface; and if the whole engine had been built on one base-plate, self-contained, so that the back of the engine and the pedestals of the front would have floated about together. The base-plate however had not been designed properly for such foundations; it had only a narrow edge underneath, bearing too severely on the edges of the mats, and gradually wearing and compressing them; and it was built up of several stools, which worked loose at the joints and allowed different parts of the engine to strain out of their strict relative positions: so that the engine did not answer well as a machine. It answered well in respect of the economical use of gas, but not as a machine; and it gave a good deal of trouble. Having visited last night the electric lighting station in Belfast, he had seen that hardly any of the troubles he had mentioned were experienced here, because the engines here took in gas four times for two revolutions, instead of only once for two revolutions. Therefore the flow of the gas through all the pipes, both the supply and the exhaust pipes, was more continuous and less impulsive. As far as he could judge from what he had seen, he should be inclined to say that, from a mechanical point of view, the Belfast electric station was extremely good, and was a great step in advance as compared with what had been done at the Yorkshire College, Leeds.

Mr. C. Frewen Jenkin considered the results obtained by the mode of governing the engines deserved attention. The diagram, Fig. 26, Plate 76, certainly showed that the governing was admirably adapted for keeping the speed constant. The diagram, Fig. 31, Plate 78, showed the gas consumption in a remarkable manner. The bottom line was almost level: that is, the total gas consumed per hour, whether working with a load of nearly 120 or of a little below 24, was almost constant. The governing had been described as being effected by the throttling of the gas; but it was clear from Fig. 31 that almost as much gas was being used at no load as at over-load; and the governing he therefore considered must be due to the stratification mentioned in the paper, and not to the throttling of the gas. Moreover the stratification was described as enabling a poor mixture of gas to be exploded; but it seemed clear that the action was exactly the opposite, because the mixture of gas was almost as rich at no load as at high load. What the stratification did was to prevent a good mixture of gas from burning properly: so that he was almost led to suspect that the gas must be exhausted unburnt through the exhaust pipe. He should be glad to know whether it had ever been found that the gas was burning as it went up the exhaust pipe: that was an accident which was known to happen occasionally in the working of gas engines.

Mr. T. HURRY RICHES, Member of Council, enquired why so low a voltage had been adopted. Of course for short leads, distances of only 200 or 300 yards, he could conceive that the low pressure was an advantage, because in using the current for motors there was less danger of injury to life and not much loss of current; but it seemed to him that in a station such as this in Belfast, where considerable extensions might occur and long distances might be necessary, there must be an objection to such a low pressure as only 220 volts.

Mr. McCOWEN said that, although he could not give the exact capital cost of the vertical and horizontal gas-engines (page 329), the high-speed vertical engines coupled direct to the dynamos were somewhat cheaper than the horizontal engines driving through ropes. Besides this there was a further considerable advantage in the smaller floor-space occupied by the vertical direct-coupled engines; the relative space was 3·6 square feet per kilo-watt for the rope-driving sets, against 1·3 square foot per kilo-watt for the direct-coupled sets.

Pending tests of the high-speed vertical engines with the Belfast gas (page 329), tests which he had carried out at the makers' works in Glasgow had given a consumption at full load as low as 22·6 cubic feet of gas per E.H.P. per hour. [See also page 344.]

In regard to the relative amount of light obtained from a given quantity of gas, by using it in ordinary gas burners, and by using it in a gas engine to supply the power for producing electric light (page 329–30), he had found that one unit would supply 33⅓ 30-watt lamps of 8 candle-power for one hour, that is 266 candle-power for one hour; and taking the figure he had given (page 322) as the result of the first year's working, namely 53·7 cubic feet of gas per unit sold, the light produced was 266 ÷ 53·7 = 4·95 candle-power per foot of gas per hour. The same gas used in ordinary burners (No. 6 Bray special) gave from 2¾ to 3 candle-power per cubic foot of gas per hour.

There had been no trouble from internal deposit in the gas engines (page 330). Some of them after running about 1,500 hours showed very little deposit indeed, and might have run double the time without any inconvenience. The exhaust valves required facing up now and then. Two Crosby indicators were used in the tests recorded in Tables 1 and 2, placed at each end of the cylinder. The mechanical efficiency of the engines, or (I.H.P. at full load − I.H.P. when running light) ÷ I.H.P. at full load, was as follows:—

	Full load.	Running light.	Mechanical Efficiency.
No. 6 Tandem engine	120·5 I.H.P.	18·8 I.H.P.	84·4 per cent.
No. 2 Single-cylinder	57·6 ,,	8·2 ,,	85·7 ,, ,,

The I.H.P. at full load was taken as that given in Tables 1 and 2 at the highest load in each case; but it would be possible to get more power out of the engines.

As to whether the duration of the test was long enough (page 330), observations were made every 2½ minutes; and the time was taken by a stop-watch, and was correct to less than a second. Two men were indicating, a third was measuring the current by means of a potentiometer, a fourth reading voltage on a Kelvin electrostatic instrument, and a fifth taking speeds and gas and water readings; and as the load was kept nearly constant, he thought the results arrived at were fairly reliable. The quantity of circulating water was varied by means of cocks on the supply to each engine. Electrical ignition (page 331) had not hitherto been tried.

From the low gas consumption of only 20 cubic feet per electrical horse-power per hour, obtained in tests on an engine at the Yorkshire College, Leeds (page 331), it was evident that the gas used had a high calorific value, and that the engine was efficient. It had been mentioned however by Mr. Wicksteed (page 337) that the engine "answered well in respect of the economical use of gas, but not as a machine." Economy in gas consumption was highly desirable; but he considered that good mechanical running should certainly come first in an electricity supply station. It would be interesting to have particulars of the tests, giving the gas consumption per electrical and per indicated horse-power per hour, and the efficiencies at the different loads. Much better results than those given in Table 1 had been obtained in the the trials conducted

(Mr. McCowen.)

at the makers' works in Kilmarnock: which was no doubt due to the higher calorific value of Kilmarnock gas. The best result with Belfast gas in Table 1 was 27·4 cubic feet per E.H.P. per hour at full load; whereas in Kilmarnock the consumption at full load came out at 23·6 cubic feet per E.H.P. per hour, and he believed the engines were working more efficiently now than when they were first erected.

In regard to getting steady running with heavy fly-wheels on both engine and dynamo (page 332), and using a belt drive, that was an easy matter, and was what would naturally be done, when putting in a single set of machinery to supply electric lighting. But when a number of sets of machinery were to be run in parallel, it was a little different. Through the courtesy of Mr. Dashwood, electrical engineer to the Belfast Exhibition of 1895, he had had the opportunity of carrying out some interesting experiments on six different makes of gas engines, all of 14 nominal horse-power, which were employed for driving dynamos for lighting the Exhibition. They were all placed side by side together with a steam engine, and leads were brought from each dynamo to a main switchboard, arrangements being made for running each set on a separate circuit, or all in parallel. These engines he understood had all been supplied for electric lighting. The method of governing in all was by missing an explosion. The engines all ran steadily when on their separate circuits. But when the dynamos were switched into parallel upon a common omnibus bar supplying the total load, it was impossible to tell what any individual machine was doing, for the load was so thrown about from one machine to another that the ammeter needles were swinging over the whole scale of the instruments; and, but for the fact that there were no minimum automatic cut-outs in the machine circuits, the probability was that one or other of the machines would have cut out, leaving the others overloaded.

The rope drives in the Belfast station were most satisfactory. They had no slip, and he was glad to say they required none, to get steady lighting. There was no more swing in the ropes than if they were driven by a steam engine.

In stating that the cost of stores compared favourably with steam-driven stations (page 333), he had taken the published results for last year for six steam-driven stations of about the same output, and from the following figures he certainly thought the Belfast result was favourable:—

Sunderland,	units sold	95,446,	cost of stores per unit	0·10	penny.
Southport,	,, ,,	89,979	,, ,, ,,	0·21	,,
Bolton,	,, ,,	94,914	,, ,, ,,	0·23	,,
Belfast,	,, ,,	82,771	,, ,, ,,	0·23	,,
Lancaster,	,, ,,	78,264	,, ,, ,,	0·34	,,
Newport, Mon.,	,, ,,	91,557	,, ,, ,,	0·45	,,
Leicester,	,, ,,	77,797	,, ,, ,,	0·46	,,

No complaints had been received as to vibration or noise (page 334); nor had any of the troubles been met with, which had been experienced at the Yorkshire College, in respect of interference with the gas supply to the neighbourhood, or of the rattling of loose window sashes. The engines were simply bolted down to their concrete foundations, and the vibration was so slight as not to affect the employment of mirror galvanometers in making electrical measurements in the station. There had been complaint as to deposit from the exhaust gases (page 336); but that had occurred during the testing of an engine before the exhaust uptake was completed; immediately that the pipe was carried up to the proper height, there were no more complaints.

The curve for total gas consumed per hour in Fig. 31, Plate 78, might be a little misleading (page 337), on account of the small scale to which it was plotted vertically. It was true that at low load of about 24 per cent. the total gas amounted to as much as 74 per cent. of what it was at high load of about 118 per cent., as shown in tests 5 and 1 in Table 2 (page 325); but then the same tests showed that the indicated horse-power at low load was 23·8 I.H.P., against 57·6 I.H.P. at high load, or 41 per cent. There had been some back firing in the exhaust, before the adjustments referred to in page 312–13 were made; but this was done away with after these adjustments had been made, whereby prompt and regular ignition was obtained, as shown in Figs. 26 and 27, Plate 76.

(Mr. McCowen.)

With regard to the reason why a low pressure was employed (page 338), no doubt one of the reasons why a high-pressure alternating system had not been adopted was that at the time there were difficulties in getting satisfactory parallel running with alternators driven by gas engines.

The PRESIDENT invited the Members to accord to Mr. McCowen a hearty vote of thanks for his valuable paper, which had also elicited a discussion that was both practical and useful.

Professor JOHN GOODMAN, in response to the author's desire (page 339), sent the particulars given in Table 6 of the experiments on the two Premier gas engines at the Yorkshire College, Leeds.

To what had been said by Mr. Wicksteed (page 335) respecting the trouble experienced with the larger of these two engines, it might be added that both of them had had to be placed in a small room in the basement of the College, where the space was so small that there was only just room for the attendant to squeeze in between the two, their outer fly-wheels being close to the walls. The engines had at first been bolted down to the concrete foundation; but the noise and vibration from them were then so serious that they had been lifted, and underneath them had been placed closely-woven cocoa-nut mats about six inches thick. In order to distribute the load, a piece of old boiler-plate was placed between the engine bed and the mats. This practically cured the noise and vibration inside the building. The noise of the exhaust, as explained by Mr. Wicksteed, had been easily overcome by taking out one length of the 6-inch exhaust pipe, and inserting a length of 18-inch pipe filled with gravel and baffle plates. In consequence of the windows having to be nearly closed up for preventing nuisance to neighbours by the sucking in of the air, the engine room got unpleasantly hot, sometimes over 150° Fahr.; but efficient ventilation was secured by coupling up the Meldrum and Loidis blowers on the boilers near at hand, and cutting an airway through to the other side of the building. After all these troubles had been ended, a serious mishap had occurred to the larger engine: the nuts

TABLE 6.

Experiments on two Premier Gas Engines at the Yorkshire College, Leeds.

Calorific value of gas at 32° Fahr. and at 14·7 lbs. per square inch, 652 British thermal units per cubic foot.

Price of gas 2*s.* per thousand cubic feet.

			Large engine.		Small engine.	
			Full power.	Half power.	Full power.	Half power.
Duration of experiment		hours	2	2	1	1½
Mean revolutions per minute		revs.	152·8	156·8	253	224
Mean Indicated Horse-Power		I.H.P.	61·5	39·5	17·6	8·12
,, Electric ,,		E.H.P.	47·5	23·2	13·5	Not taken
,, Brake ,,		B.H.P.	Not taken	Not taken	Not taken	6·86
Electric H.P. ÷ Indicated H.P.		per cent.	77·2	58·7	76·7	—
Brake H.P. ÷ Indicated H.P.		per cent.	—	—	—	84·5
GAS USED, including ignition, at 32° Fahr. and at 14·7 lbs. per sq. inch	per I.H.P. hour	cubic feet	15·27	20·9	15·2	26·75
	,, E.H.P. ,,	cubic feet	19·77	35·6	19·8	—
	,, B.H.P. ,,	cubic feet	—	—	—	31·76
Ratio of air to gas by volume			12·7 to 1·0	14·3 to 1·0	9·5 to 1·0	9·9 to 1·0

(Professor John Goodman.)

on the big end of the connecting-rod shook off, presumably through their not having been properly locked by the attendant, who had recently removed the brasses in order to let them together; moreover the requisite split-pins through the ends of the connecting-rod bolts had unfortunately not been provided. The engine was completely wrecked, the cylinder end forced out, the piston smashed, the bed broken, and the connecting-rod bent. The crank-shaft was also damaged, though at the time the injury was not considered serious; but about six months afterwards it broke off short in the neck close to the crank web. In spite of all these troubles and difficulties, the engine was now working excellently, the light was perfectly free from flickering, and the total cost of the lighting was about one penny per unit, exclusive of wages; no extra labour had to be employed, because the engine was attended to by one mechanic and a stoker, both of whom were previously employed to look after the college boilers, &c.

Mr. McCowen sent the results given in Tables 3 to 5 (pages 326–8) of tests of the high-speed vertical direct-coupled engines, taken in 1896 at Glasgow and at Belfast. In Table 5 tests 1–6 were taken on 27th March, and tests 7–12 on 28th March; the latter consisted of a six hours' continuous run at full load. In Table 3 tests 1–5 were a five hours' continuous run at full load; tests 1–7 were taken on 29th May, and tests 8–13 on 30th May.

The calorific value of Glasgow gas, as determined by himself with a Jünker gas calorimeter on 30th October 1896, that is, on a different date from the tests in Tables 3 and 5, was 750 British thermal units per cubic foot, at 14·7 lbs. pressure per square inch and 60° Fahr. As calculated by Mr. Dugald Clerk from Professor Percy F. Frankland's analysis of gases (1882–4) the calorific value per cubic foot at the same pressure was 762 thermal units at 62·6° and 810 at 32° Fahr.

Belfast gas, as also determined by himself with the same calorimeter on 4th November 1896, simultaneously with the tests in Table 4 (page 327), had a calorific value of 570 British thermal units per cubic foot at 14·7 lbs. pressure per square inch and 60° Fahr.

UNUSUAL CORROSION OF MARINE MACHINERY.

By Mr. HECTOR MACCOLL, of Belfast.

Corrosion in Marine Engines and Boilers is usually confined to well-known parts, is not rapid in its action, and may be prevented or stopped by the adoption of suitable measures. In a recent instance its action was so wide-spread, so rapid, and so powerful, as to render a short description of it somewhat interesting to engineers.

Steamer.—The steamer "Glenarm" is a steel vessel of the long raised quarter-deck type, built in Belfast in 1890 for the Antrim Iron Ore Co.; and is engaged in their trade between Belfast and ports on the north-east coasts of Scotland and England. She is classed 100 A 1 in Lloyd's register, with a dead-weight capacity of about 800 tons; and her machinery consists of three-crank triple engines with cylinders 17, 27, and 44 inches diameter by 30 inches stroke, a three-furnace single-ended boiler of the usual type loaded to a pressure of 165 lbs. per square inch, and a single-furnace horizontal multitubular donkey-boiler. The shafting and other forgings are all of iron; the boilers are of steel, with iron tubes.

Submergence.—On Tuesday 24th December 1895 this steamer, carrying a cargo of about 650 tons of "burnt ore" from Irvine to the Tyne, struck on a rock in the Sound of Mull, and was at once beached in Scallaster Bay, where the sea stood a little over her after-deck at low water, and close up to her bridge deck at high water. On the following Monday, 30th December, after having been submerged six days, she was pumped out and raised. On the same day steam was got up in the main boiler; but when about 30 lbs. pressure had been reached, the steam valve on the donkey pump blew out, and it was found that the copper at the bend of the donkey feed-pipe next the main boiler had disappeared; fires were therefore drawn, and the boiler blown off. On Friday, 3rd January 1896, all leaks having been so far reduced as to be under control of the salvage pumps, the vessel left in tow for Belfast where she arrived early on Saturday morning, all the salvage operations having been successfully conducted by Capt. Bachelor of the Liverpool Salvage Association.

Cause of Corrosion.—On examination the machinery was found to present an extraordinary appearance: all wrought-iron work was deeply and roughly corroded, and planed cast-iron work rendered so soft as to be easily cut with a knife. These unusual effects were undoubtedly caused by the cargo of "burnt ore"; and the following explanation has been contributed by Mr. S. Courtney, chemist, of Messrs. Francis Ritchie and Sons, Belfast, who investigated the subject at the request of Mr. Robert Browne, secretary and manager of the Antrim Iron Ore Co. "Burnt ore is the residue from the manufacture of vitriol from sulphur pyrites, and is generally found to contain about 4 per cent. of sulphate of copper, together with a little sulphate of iron, due to the sulphur not having been completely burnt out of the ore and becoming oxidized into sulphates. The sulphate of copper would be more or less completely dissolved in sea water; and as the latter contains a considerable quantity of chloride of sodium or common salt, this would re-act on the sulphate of copper, forming sulphate of sodium and chloride of copper. The sulphate of copper and chloride of copper are both soluble in water; and a solution of either, or both, dissolves wrought-iron and cast-iron. The chloride is more energetic in its action than the sulphate; but in time a solution of either, no matter how weak, will dissolve an atom of iron for every atom of copper present. Every hundred tons of cargo contained as much sulphate of copper as would, if available, dissolve nearly 32 cwts. of metallic iron. The burnt ore might also contain a small quantity of free sulphuric acid, which would combine with the soda of common salt in the sea water, and set free hydrochloric acid; and the latter would rapidly act upon copper or brass."

Extent of Corrosion.—On the condition of affairs being discovered, the engines and boilers, as well as the hull, were at once opened up for survey, the underwriters being represented by Mr. Henry H. West of Liverpool, and the owners by Mr. James Maxton of Belfast; the entire work on the hull and machinery was afterwards carried out under the direction of the latter. The general condition of the engines was that wrought-iron work had been penetrated by corrosion to a depth of about 3-32nds inch, and planed cast-iron so softened that 1-8th inch had to be taken off before a hard surface was regained. Surfaces in bearing contact, or with oil between them, and all painted surfaces, were completely preserved. The detailed condition of the various parts, and the measures taken to restore them, were as follows.

Cylinders.—These had partially filled through the hot-well, and from the drain cocks being open. The lower part of the intermediate cylinder was softened for 12 inches up, and was re-bored $\frac{1}{4}$ inch larger in diameter, and the piston altered to suit. The piston-valves and liners in the high-pressure and intermediate cylinders were softened at their lower ends; the liners were re-bored, and the valves fitted with new rings. The lower edges of the low-pressure slide-valve and face were also softened; the valve was planed, and the lower bar of the face chipped off and replaced by a brass strip pinned on. In all other respects they were sound and good.

Piston-Rods and Connecting-Rods were turned all over, reduced 3-16ths inch in diameter, and the former fitted with new neck and gland bushes.

Guides had 1-8th inch planed off them before a hard surface was reached; and the guide shoes were lined up to suit.

Valve Gear is of the Hackworth type. The valve-spindles and various rods were turned all over, to remove the deep pitting; the angle blocks had their planed surfaces reduced 1-8th inch, and the various parts lined up to suit.

Shafting.—The crank webs were deeply corroded; but as there was ample strength, they were filled with "hard stopping" and painted. The shaft journals and crank pins were pitted longitudinally in the exposed spaces between the white-metal strips, and were also pitted transversely at the clearance spaces next the crank webs; these were cleaned out, filed up, and the bearings adjusted. The thrust shaft was much corroded at the exposed parts of the collars and journal; it was turned all over, and the horse-shoes and bearing were re-filled with white metal. The intermediate length of tunnel shafting was much corroded at the exposed part of the journal; and as it was also reduced by wear, a new journal was turned further forward, and the bearing shifted to suit. The propeller and propeller-shaft were found in good order.

Auxiliaries.—The centrifugal pumping engine was considerably wasted in the rods, guide, &c.; and was treated like the main engines. The duplex pumping engine and donkey-boiler pump were so seriously corroded as to be useless, and they were replaced by new. The brass steam-valve and one pet-cock of the duplex pumping engine were curiously wasted into holes; and the check valve and seat on the main boiler had the appearance of some substance, probably zinc, having been sucked out of them.

Pipes.—From the appearance of the donkey copper feed-pipe it was feared that all the copper pipes were seriously affected. A similar bend in the main feed-pipe was therefore sawn through, but was found to have suffered no deterioration. All the pressure pipes however were taken down, tested, and annealed; no defects were detected, and they were all re-placed. But in putting together the various steam and vacuum gauges the small connecting pipes were found in several places to be curiously wasted below the coupling nut.

Small Details.—It is unnecessary to enumerate the bolts, nuts, cock handles, spanners, and such small details, which were wasted into mere shadows of their former selves, and had to be renewed.

Boilers.—The safety-valves of the main boiler having been eased when the vessel was beached, the boiler had filled with water; and the condition of both boilers looked serious. The front end plate of the main boiler was considerably wasted: the furnaces, which are of the spiral corrugated type, had corrosive scores running in the direction of the corrugations; and the tubes were covered with a deposit of what appeared to be pure metallic copper. In the end however, after careful drilling and gauging, it was found that an unexhausted margin remained in all except the tubes. These were all found to be seriously corroded in both boilers, and every tube was therefore cut out and renewed; after which the boilers were satisfactorily tested.

Steam Trial.—Although the utmost vigilance and care had been exercised in examining as far as possible every point and detail, latent defects might have existed; and it was not with complete confidence that steam was again raised and the machinery tried. Neither then however, nor in the months of continuous service which have since elapsed, has the slightest defect been perceived; and the machinery is now, thanks to its thorough overhaul, working with the efficiency and economy which it possessed when new.

Conclusions.—The lessons to be learnt from this experience are probably obvious enough. Some of them are for the shipowner rather than the engineer, and therefore need hardly be referred to here; but it may be well to emphasize two of the others.

First, the advantage of having, in marine engines and boilers, a small margin over the actual requirements for strength. In the various rods, shafts, and similar parts, such a diameter as would allow them to be skimmed up; in the cylinders, valves, &c., such thickness as would allow them to be bored or planed afresh; and in the furnaces, combustion chambers, and stays, a slight excess of thickness over that required by the rules.

Second, the advantage of good paint. Many engineers prefer polish to paint; but in this instance the latter truly cost little, and was worth much.

Discussion.

Mr. MacColl exhibited a collection of specimens of the corroded parts which had had to be replaced new in restoring the steamer for service. They included the brass steam-valve and pet-cock of the duplex pumping engine, and its check-valve and seat on the main boiler; donkey copper feed-pipe; gauge connecting-pipes; bolts, nuts, cock handles, spanner, fire-rake, oil drainer; iron boiler-tube, and deposit of metallic copper collected therefrom; and a drag link for valve gear. Curiously enough, he pointed out, some pieces of iron had been left untouched by the corrosion, owing he presumed to some peculiarity in the structure of the metal. Another curious thing was met with in the connecting-rods; a brass tube for lubricating the crank-pin ran down all along the inner side of each rod, and was clamped upon it with brass clips; and down the whole line of the tube the original polished metal stood up from the adjoining corroded surface of the rod, and was perfectly clean and still polished, both under the clips which clamped the tube to the rod and also along the whole line of the tube itself.

Since the present paper had been written, he had read in the Institution Proceedings (1878, page 116) the account of the raising of the wreck *Edith* in Holyhead harbour; and after she had been submerged two years and a quarter it had been found that the engines were very little the worse; the piston-rods were turned up, and that was the main repairing that had to be done; the other parts were only just cleaned up (pages 135–6). From the samples now exhibited would be seen the contrast presented by the corrosion that had occurred in six days in the instance described in the paper. He had also been told of a steamer which had been under water in the Gulf of Mexico for more than three years, and after she had been raised her machinery had been cleaned, and she had gone away without its requiring repair.

Mr. Henry H. West had noticed a peculiarity of the corrosion in the boiler, in which, as stated in the paper (page 348), the furnaces were of spiral corrugated make, and had corrosive scores running in the direction of the corrugations. It was remarkable that the convex side of the corrugations, whether that was inside in the furnace or outside in the water space of the boiler, was the most severely pitted. In the same way the flanged front and back end-plates were most corroded on the convex side of the flange. This showed apparently that the steel suffered most where its texture had been most opened in the course of the manufacture of the furnaces and plates, thereby seemingly exposing the grain of the metal more freely to the corrosive action. The upper side of the iron tubes was badly pitted, while their under side remained apparently just as it had been previous to the accident. This he believed was due to the deposit of copper on the upper side of the tubes; there was apparently a considerable quantity of copper in solution in the boiler, which was found deposited in moss-like spikes all over the upper half of the circumference of each tube. This large quantity of copper he considered must have come from the cargo. He was himself much interested in the whole of the occurrence, because he had examined the vessel on behalf of the insurers; and in the course of their negociations it had been arranged to settle with the owners by payment of a lump sum, instead of running the risks of undertaking a complete repair. From the information given in the paper as to what had been actually done in the way of repairs, he was now of opinion that the settlement had been a good bargain for the owners. From his own point of view also he thought it had proved advantageous for the underwriters; for had they been obliged to repair the ship and carry out her complete reinstatement, he was certain it would not have been done for the sum eventually settled upon. In that case he had no doubt all the repairs so ingeniously carried out by the author would have been looked upon in a somewhat different light: instead of the piston-rods and connecting-rods being accepted after having been skimmed over, they would have been required to be replaced by new; and new cylinders, new crank-shaft, and new thrust-shaft would have been insisted upon. Another circumstance which had confirmed him in his opinion that in such occurrences it was sometimes a wise course to settle for a lump sum, was that in this instance it so happened

(Mr. Henry H. West.)

that the settlement was arrived at before the engines had been completely opened out. At the time the settlement was made, there was no knowledge that there would be anything to do inside the cylinders; and until reading the paper he had not known that they had even had to be bored out. From experiences of this kind, it was natural to come to the conclusion that it might sometimes be wise to try to effect a compromise before knowing all the facts.

With regard to the cause of corrosion, he thought the paper had told practically what the origin of the mischief had been. In his own experience a large number of ships had sunk from time to time, in regard to which he had acted sometimes for the owners and sometimes for the underwriters, and had thus had occasion to investigate the circumstances from both sides. In the majority of cases he had found that there was but little to do in the way of repairs to machinery when a ship had simply sunk; it was when she had stranded that there was generally a great deal to do. When she had simply sunk, cleaning up the tarnished surfaces of the machinery and getting steam up seemed to be about all that had to be done. The author had mentioned (page 350) two instances in which vessels had been submerged, one for $2\frac{1}{4}$ and the other for 3 years, and there had been little or nothing to do to the machinery after raising. In the present instance there had been submersion for only six days, with the most serious waste and corrosion. This he thought pointed to the fact indicated in the paper, that the cargo had a great deal to do with it; and also to the necessity for underwriters to take into consideration not simply the construction of the ship herself, but likewise the employment in which she was engaged.

The PRESIDENT asked which metal showed the most corrosion in the instance described in the paper.

Mr. WEST replied that the wrought-iron and steel showed the most. The cast-iron suffered on the surface wherever exposed; and it was remarkable to notice how along the arris of a casting, where the paint had naturally got scrubbed off, the corrosion had run in right along the edge, while on each side of the edge the metal was protected by the paint; there was thus a sort of groove all along the edge, and the two surfaces on each side of it were maintained perfectly free from corrosion.

Mr. Henry Davey, Member of Council, said it was interesting to know that what had taken place during the corrosion of the machinery described in the paper was actually a commercial operation in different parts of the world. In several parts of Cornwall the water pumped from the mines contained in solution sulphate of copper. It was stated in the paper that a solution of sulphate of copper would dissolve an atom of iron for every atom of copper present. Copper was recovered from the mine water by means of scrap-iron, which was simply put into a long trough, and the water was allowed to run over it; the result was that the sulphuric acid in the sulphate combined with the iron, forming yellow ochre, which flowed away in the water, while the metallic copper was deposited in the place of the iron that had been dissolved. To render the operation continuous, it was necessary to devise some means which would remove the metallic copper as fast as it was deposited on the surface of the iron, in order that the latter might be exposed afresh for the further action to take place; and here he thought would be found the explanation of some of the caprices which appeared in the local corrosion that had taken place in the machinery described in the paper. Where the water was agitated and the metallic copper was washed off so as to expose a fresh surface of iron, there the corrosion would go on continuously, as long as the agitation continued to wash off the deposited copper. This was exactly the principle which was adopted in recovering copper from the peculiar water pumped in metalliferous mining operations. The water was not allowed to flow gently over the surface of the iron, but was made to fall from a little height, just sufficient for the impact of the water on the surface of the iron to wash off the particles of copper as fast as they were deposited. Thereby the operation was rendered continuous. The great local corrosion which had taken place in the machinery he had no doubt showed where the water had been agitated by the motion of the sea; while in places where the water had been kept free from

(Mr. Henry Davey.)

agitation, the deposit of copper on the surface of the iron would prevent any further corrosion. The whole occurrence described in the paper was so exceedingly exceptional, that he could hardly concur in the desirability of putting a sufficient extra thickness of metal in all parts of marine engines, thereby increasing their weight and the expense of working the ship, in order to provide against an extraordinary contingency, of which the present was probably the only example known.

Mr. MacColl said the small margin or extra size, the advantage of which he had emphasized at the conclusion of the paper, was no more than that which every engineer carried out in his own work. Every cylinder had to be bored some time or other, if it worked long enough; every valve had to be faced up; rods had to be skimmed up; piston-rods in particular had sometimes to be skimmed up at the end of a couple of years, apart from any such accident; their duration depended mainly upon the kind of packing used. The occurrence described in the paper furnished a good illustration, he considered, for showing the necessity of providing for such wear and tear.

The President had great pleasure in presenting the thanks of the Members to Mr. MacColl for his interesting description.

NOTES ON THE INTRODUCTION AND DEVELOPMENT OF ROPE DRIVING.

By Mr. ABRAM COMBE, Falls Foundry, Belfast.

Introduction of Rope Driving.—So much has been said and written on the advantages and application of Rope Driving, and so many data and formulæ have been published from time to time, that it is hardly necessary to add to the information already available in these respects; but as rope driving emanated from Belfast, and has now grown to such large proportions in the industrial transmission of mechanical power, a short history of its origin, introduction, and development, may prove of interest on the present occasion. Its introduction is due to the late Mr. James Combe, who in 1856 applied an expanding pulley with V shaped sides to the differential motion of flax and tow roving frames, as shown in Plate 80. The expanding pulley was driven by a round leather rope from a driving pulley grooved with a V shaped groove. In the course of his experiments in perfecting this motion, he was struck by the large amount of power obtained from round ropes working in V shaped grooves; and this led him to try their application to the transmission of larger powers. With a view of arriving at the most effective angle for the grooves, a series of experiments were made in the Falls Foundry works in the following manner. A pulley, fixed from revolving, was made with a number of grooves, each having its sides sloping at a slightly different angle from the others; ropes were then laid over these grooves with weights hanging from them at one end and counterbalance weights at the other; and the effect produced on the biting power of the rope in the groove by increasing and diminishing the weights and the counterbalance weights was carefully noted. The object was to determine in a practical manner the most suitable angle of groove for a driving rope, so that the rope should neither slip nor yet bite too much into the groove; and the angle chosen after the above simple experiments, namely 45°, was adopted in the first pulleys set to work, and is at present generally used for rope driving under ordinary conditions.

After several years' use of grooved pulleys and ropes for driving from the main shaft of one of the workshops at the Falls Foundry to that of another, the advantages of rope driving under certain conditions were found to be so great that, on the occasion of replacing one of the main engines in the beginning of 1863, rope driving was adopted for transmitting the entire power of the engine, amounting to over 200 horse-power, from the second motion shaft to the principal shaft. This is the first instance of rope driving being used for a main drive of such importance, and the original pulleys are still in existence and working daily, as shown in Plate 81.

Material of Ropes.—About that date round ropes made of leather strips were generally used. These however were found to have the objection that they were liable to untwist, and the ends of the leather strips were apt to fly out during the working and cause trouble. Moreover the strips of leather being cut out of the hide in a spiral were less strong where cut from the smaller diameters, and were liable to break at those parts. Manila ropes were then tried with good results, and leather ropes gradually gave place to ropes made from manila.

Relative Diameters of Ropes and Pulleys.—It was early recognized by the late Mr. James Combe that it is necessary to proportion properly the diameter of the ropes to the diameter of the pulleys on which they work; and he adopted the following minimum diameters of pulleys for the various sizes of ropes:—

1¼ inch diameter rope, 3 feet diameter pulley; ratio 1 to 28·8
1½ ,, ,, ,, 4 ,, ,, ,, ,, 1 to 32·0
1¾ ,, ,, ,, 5 ,, ,, ,, ,, 1 to 34·3
2 ,, ,, ,, 6 ,, ,, ,, ,, 1 to 36·0

Experience has shown that the results have not been so satisfactory when ropes of the above sizes have been used on pulleys smaller than the above minimum diameters.

Power transmitted.—When working under ordinary conditions the following simple bases were taken from which to calculate the power that each of the foregoing sizes of rope would transmit for each 100 revolutions per minute made by the pulley upon which it is working:—

Rope $1\frac{1}{4}$ inch diameter on a 3 ft. pulley would transmit 5 I.H.P.
„ $1\frac{1}{2}$ „ „ „ 4 „ „ „ 8 „
„ $1\frac{3}{4}$ „ „ „ 5 „ „ „ 11 „
„ 2 „ „ „ 6 „ „ „ 15 „

and for other sizes of pulleys the power transmitted is calculated to be increased in direct proportion to the diameters of the pulleys. When working under the most advantageous conditions—for instance, where the ropes are running horizontally at good speeds, with the pulleys at a proper distance apart, and with the bottom rope acting as the driver—the above bases may be increased by 20 to 25 per cent. with safety. On the other hand, when the ropes are working under unfavourable conditions, with centres of pulleys too close together or ropes running vertically, these bases must be diminished by 20 to 25 per cent. The exact amount of increase or decrease on these standard bases has to be determined in each individual instance, according to the circumstances under which the ropes are working.

Speed of Ropes.—The speed originally adopted as being the most advantageous was about 3,300 feet per minute. This speed has since been far exceeded in many instances; but it is a question whether advantages have been reaped proportionate to the power gained by the increased speeds. On the contrary the gain of power by increased speed is largely counteracted by loss of power from atmospheric friction and from centrifugal action; and when this loss is taken into account, along with the increased wear and tear on the ropes and bearings, the speed originally adopted, and speeds within certain limits of it, have been found to give the best results.

Extended form of Rope Driving.—The new method of driving soon became known to several English and Scotch engineers, who joined in its further introduction and development. An extended form of main rope driving from the second motion shaft to the various lines of shafts in a flax mill is shown in Fig. 15, Plate 87. This drive was started in July 1864 in the Hilden Mills of Messrs. William Barbour and Sons, Lisburn, and is transmitting 600 I.H.P. Plate 82 represents one of the earliest examples of rope driving from the fly-wheel of the engine itself. This drive, erected in 1873 at Owen O'Cork Mills, Belfast, was designed by Messrs. Combe and Barbour, by whom also the pulleys were made, the fly-wheel being supplied to their instructions by Messrs. Hick, Hargreaves and Co.

Cotton Ropes.—Later on in certain districts, especially those in which the cotton industry prevailed, cotton ropes began to be used. These have the advantage of being rather more pliable than manila ropes, especially when the latter are new. The relative merits of ropes made of manila and those made of cotton have frequently been discussed; but experience has shown that, if the pulleys are properly designed and applied, and if the ropes are the proper diameter, good results are obtained, whether the ropes are made of manila or of cotton.

Shafts not parallel.—One of the great benefits that were found in rope driving at a comparatively early stage was that ropes could be applied with advantage to transmit power between shafts that were not parallel. In 1875 the drive shown in Fig. 7, Plate 83, was put up in the works of Messrs. Combe and Barbour to drive 100 I.H.P. from one shaft to another which was not quite parallel with it. Here the angle between the shafts is about 3°, and the ropes were applied without making any alteration in the form of the grooves. When however it is desired to employ ropes for driving shafts at a greater angle, the grooves in the pulleys are altered to the section shown half full size in Fig. 8, which was introduced about 1875, so as to allow the ropes to enter and leave the grooves without greater friction on their sides than when the shafts are parallel.

Endless Rope for Close Shafts.—In 1878 grooved pulleys and rope driving were introduced to replace pairs of large geared wheels, which from one cause or another were giving trouble; for example, in places where they were used to combine the power from a steam engine with that from a water wheel, or to combine the power from two engines working under slightly different circumstances. Here the centres of the wheels were so close together that ropes, if applied separately in the ordinary way, would have been too short for effective driving, and there would have been difficulty in putting equal tension upon each of the several ropes. Consequently, in order to secure a proper length of rope and equal tension, a single continuous rope was used, as shown in Plate 84, which was laced round and round the pair of pulleys, passing from the first groove of the driving pulley to the first of the driven, thence back to the second groove of the driving pulley and on again to the second of the driven, and so on; and a tension pulley was added for leading the rope back from the last groove into the first.

Rope Fly-wheels.—The continued rapid extension of rope driving, and more especially of driving direct from the fly-wheel of the engine to the various shafts, led to designing fly-wheels to suit the high speeds. In Plate 85 is shown a rope fly-wheel designed by Mr. James Barbour in 1879 to meet the special requirements. The peculiar advantage of this method of constructing fly-wheels is that, instead of depending solely on a cast-iron arm for connecting each segment to the nave, a strong wrought-iron bolt B is used, Fig. 13, Plate 86, which passes down through the middle of the tubular cast-iron arm, and connects each segment directly with the nave; consequently this bolt not only receives the tensile strain caused by centrifugal force while the wheel is in motion, but it also withstands the driving home of the cotters when the wheel is being put together. When cast-iron alone is used for the arms, the driving home of cotters is a frequent source of breakage, which may not be detected until the fly-wheel gives way; whereas by driving the cotters into a long malleable-iron bolt there is less danger of fracture. The starting worm or barring engine E, shown in Fig. 14, Plate 87, is made with three pauls for barring round, in order that the motion may be continuous, instead of intermittent as it is when only one or two pauls are used.

Crossed Ropes.—It was about the same date that driving by crossed and half-crossed ropes was introduced; also that rope driving was applied to shafts working at right angles to each other, round corners, &c. In Plates 88 to 90 are shown some examples of this kind, and of the special forms of groove used.

In Fig. 16, Plate 88, is represented the crossed rope drive; and in Fig. 17 the method of putting the ropes on, so that they cross alternately right-handed and left-handed. Thus the driving side of the first rope comes next the driving side of the second where they cross; and even if they touch here, they are running in the same direction and at the same speed, and therefore do not rub against each other. Similarly the trailing side of the second rope is adjacent to the trailing side of the third, and the driving side of the third comes next the driving side of the fourth. Hence each rope, though of necessity rubbing on itself, does not rub against its neighbours. The grooves, shown half full size in the section, Fig. 18, are constructed so that their pitch is greater than twice the diameter of the rope, as a further means of preventing the ropes from rubbing against their neighbours.

In Fig. 19, Plate 89, is represented an arrangement of half-cross ropes, and in Fig. 20 the shape of groove used for enabling the ropes to enter and leave the pulleys without rubbing too much in the grooves.

In Fig. 21, Plate 90, is shown an arrangement for driving shafts at right angles to each other, by means of a pair of horizontal guide pulleys, each having a single wide groove of the section shown one-third full size in Fig. 22.

Endless Rope with Loose Guide-Pulleys.—In 1889 the arrangement of rope driving shown in Plate 91 was introduced by Mr. James Barbour. Here the driving and the driven shafts were near together, and there was not sufficient space to apply the tension pulley previously described and shown in Plate 84. A single continuous rope was therefore laced round the grooves of the pulleys, and for the purpose of leading the rope back from the last groove of the one pulley into the first groove of the other an additional single-grooved pulley was mounted loose on each shaft; these two loose pulleys were made larger in diameter than the fixed pulleys, and the rope was led from one to the other over the top of the ropes working in the grooves of the fixed pulleys. A large number of drives have been erected in this way, and all are working satisfactorily.

Endless Rope driving several Pulleys.—About the same date also a drive was erected, in which a single continuous rope was used for driving from one common pulley several shafts running at different speeds. In Plate 92 is shown an example of one of these drives, in which a tension pulley is used to bring the rope back from the last groove into the first, and at the same time to take up the slack of the rope.

In 1890 Mr. Barbour further developed the use of the single continuous rope, by applying it to the half-cross drive, as shown in Plate 93, in which is seen the peculiar method of lacing, whereby, instead of a separate rope to each groove, a single endless rope is passed round the several grooves in succession, and back from the last groove to the first, without the intervention of a guide or tension pulley.

Substitution of Rope Driving for Geared Wheels, and relative amount of Power absorbed.—In many instances existing gearing and upright shafts have been thrown out and replaced by rope driving; and where the rope driving has been properly designed and erected, the total power required for the rope driving has in none of the installations which have come under the writer's observation exceeded that which was required when driving by wheel gearing; and in many cases the power required to drive the same amount of work by ropes has been less than it was before the change in method of driving took place.

The above examples of the transmission of mechanical power by ropes serve to illustrate the development of this method of driving. Numerous variations have of course been made upon each of these plans, which have largely extended the field for the application of rope driving: so that this method of driving, which arose from such a small origin, is now widely adopted for industrial purposes. There is also no doubt that other developments will take place in the future, which will further extend its sphere of usefulness.

Discussion.

Mr. JEREMIAH HEAD, Past-President, said that during the last few weeks he had had occasion, through the instrumentality of the President, to act as arbitrator in a case in which a large number of cotton ropes used for driving dynamos had been rejected on the ground that they did not wear well. Having occupied that position for four days, listening to the arguments of counsel and to about a dozen witnesses on both sides, his own mouth being necessarily closed during the proceedings, he naturally felt he had now something to say in connection with a few of the points interesting to mechanical engineers, which had arisen during the arbitration. From the paper it would be seen that Mr. James Combe had from the first laid stress on the diameter of the sheaves round which the ropes were to work. For a $1\frac{1}{4}$-inch rope he had stated that the pulley should not be less that 3 feet diameter, and for a $1\frac{1}{2}$-inch rope not less than 4 feet. In the instance upon which he had just had to arbitrate, the ropes were $1\frac{3}{8}$ inch diameter, half way between the two sizes here given; therefore the smaller sheave ought not to be less than 3 ft. 6 ins. diameter; but as it happened it was only 2 ft. 4 ins. diameter. This he had found to be one of the chief reasons why the ropes had not worn well: in fact they had failed in a comparatively short space of time, owing mainly to the driven sheave being so small in diameter. Another reason why there had been trouble with the ropes was due to a matter which had not been referred to in the paper, namely bad splicing. In order to wear well, the ropes should be spliced in such a way that the length of the splice should be from 9 to 12 feet. The ropes which he had had to examine had been spliced in the first instance by a sailor or rigger, who had not been accustomed to that particular work, and had used much shorter splices, like nautical splices; and the result had been that the splices were continually pulling out, which had given a great deal of trouble.

It was a surprise to himself to learn that rope driving dated as far back as 1856—forty years ago. Certainly he had not heard of it in England till a much later period.

In Fig. 9, Plate 84, and others of the drawings, examples were shown of endless or continuous ropes; there was a single rope, which was laced continuously from beginning to end over all the grooves, and had only one splice in it. This he considered was an exceedingly ingenious arrangement, and was no doubt applicable to certain circumstances where multiple ropes would not be applicable. Still he thought that one of the great features of the plan of rope driving was the independence of the several ropes, each rope taking only a certain portion of the power to be transmitted: so that there was a continuity of working, which could not be had with a single strap. As soon as any individual rope was observed to be wearing or stretching unduly, it could be taken off, and the rest ought to be sufficient to carry on the work until the defective rope was repaired or another put on. Another great advantage of rope driving was that the ropes were worked slack. In that way it was evident that, while they transmitted the power, they did not try to pull closer together the driving and the driven shaft; therefore there was no undue friction, wear, and loss of power, such as arose from increased pressure on the journals for tightening a belt. Another advantage was the subdivision of the power transmitted from the driving sheave to different

(Mr. Jeremiah Head.)

parts of a mill or other works, as shown in Plates 82 and 92, and in Fig. 15, Plate 87. Then again there was no undue vibration or clatter, as there was in the old method where mills were driven by upright shafts and gearing; everything was quiet, which of course meant safety for the foundations and greater durability of the driving pulleys, ropes, and machinery.

The actual speed at which the rope was running, as far as he could see, had in itself really nothing to do with the wear. The rope itself was not conscious of the speed at which it was running, because its speed was the same as that of the circumference of the driving and the driven sheave; but the number of bends which it made per minute was an element of wear. If the rope was properly loaded, and was made of such material and in such a way that in its bending the fibres were not strained beyond their elastic limit, and sprang back completely after each bending, then he thought that the speed did not matter at all. The pitch or lay of the rope had a good deal to do with its durability, as had also the way in which it was made. If the lay was too close, the pitch was too short; and then of course the fibres were too tight, and tended to break away, or fray, as they passed over the sheaves, with the result that they would split out and form what were called "butterflies" on the rope. These were usually kept down by plastering the rope over with a composition, by which the fraying portions were hidden in the smaller part of the rope between the strands. That was only just hiding the mischief, and did not prevent the rope from gradually breaking more, and so wearing out.

The material of which the ropes were made had also been alluded to; and he had not been aware previously that they were made in Ireland of manila. In England they were made of cotton; and the best cotton for the purpose he believed was what was called "best Egyptian." The great desideratum was that the fibres should be long, that they should be equal in diameter, and that they should be elastic, not hard and brittle.

In the half-cross drives, shown in Figs. 19 and 26, Plates 89 and 93, where the driven shaft was at right angles to the driving shaft, it would be seen that the driven pulley was arranged exactly in the same plane as the axis of the driving pulley. Instead of this he should have thought it would have been better to shift the driven pulley along its shaft into such a position that the pull upon the span of the rope which was in tension should come exactly opposite its groove in the driven pulley, and that the slack or trailing span should be delivered on to the pulley at an angle. It seemed to him that, where the pull was, it should come perfectly straight upon each pulley.

Mr. A. TANNETT WALKER, Member of Council, was much interested in the name of the firm by whom rope driving had been introduced, because his father, the late Mr. Benjamin Walker, had been employed by Messrs. Combe, Barbour, and Combe in an important position exactly fifty years ago; and he was glad it had been recorded by a member of the firm that in 1856, ten years after his father had left them, they had introduced rope driving; the credit was certainly due to the late Mr. James Combe of having introduced that method of driving. Although his own firm had not had great experience in rope driving as applied to factories, they had had a good deal of experience in it as applied to heavy travelling cranes, which enabled him entirely to endorse a large part of what had been said in the paper. It was highly important to have a soft pliable material for the ropes; to have a large diameter of pulleys; and, though not mentioned in the paper, in connection certainly with travelling cranes not to have too much strain on the rope. A few years ago his brother, Mr. F. W. Walker, had introduced a double rope for driving travelling cranes; it was an endless rope, and was arranged so that two spans of it ran in one direction and two in the opposite direction, thus putting half the tension or strain on the one rope, and in consequence prolonging its life. Another important matter, he agreed with Mr. Head, was the splicing. The splice should be a long one, and skilfully made. A few years ago, when some big engines weighing 600 tons were being erected at his works, castings weighing 20 or 30 tons had had to be lifted hour after hour, and a great strain had consequently been put on the two travelling cranes.

(Mr. A. Tannett Walker.)

The greatest possible pains had been taken in splicing the ropes from time to time, in order to get a first-rate splice; and in the end this had been accomplished. The ropes were 5-8ths inch diameter, and were carefully watched. The speed ultimately adopted happened to be exactly that which Mr. Combe had found to be useful and proper, namely 3,300 feet per minute. Beginning with 2,200, it had been raised to 5,000, and then brought down to 3,300, which was the speed he now always used. With this speed, and after the splice had been properly made, the ropes had lasted nearly four years, which was a good life for a rope on a travelling crane. This successful result he attributed, firstly to the rope not being over-strained by excessive speed or tension; secondly to a proper splice being obtained; and thirdly to a proper diameter of the pulleys.

Mr. BENJAMIN A. DOBSON, Member of Council, said the subject of rope driving had always had a deep practical interest for himself as a constructor of cotton-spinning machinery, in which small ropes were often used for driving separate parts of the mechanism: so that there was an opportunity of noticing the behaviour of the small ropes, which were practically working under the same conditions as the larger ropes dealt with in the paper. Although the credit for applying rope driving for indoor work, with all the complicated arrangements for driving machinery, was undoubtedly due to the late Mr. Combe, the transmission of power to a distance by long ropes was by no means novel. In the Swiss Alps he had himself seen a mill driven by a water wheel, the wheel being in a valley, and the mill on a hill a quarter of a mile away; and it was driven by a rope which he was credibly informed, though he had no means of checking the information, had been working sixty years when he saw it. In England, especially in Lancashire, he had also watched the development of rope driving; and had had the opportunity of discussing in England and America the relative advantages of ropes and straps. The Americans were only now beginning to admit that some good could come out of Belfast in the way of rope driving; on this subject they were rather changing their ideas. In the United States he had lately seen an installation of ropes, where previously nothing would have been thought of but wide leather straps. On the proportions of the diameters of ropes and pulleys, some engineers would perhaps hardly agree with the ratios given by Mr. Combe (page 356); but he himself went still further. Having made some experiments five or six years ago, which were based upon ropes of small diameters, and were subsequently carried out with ropes of larger diameters, he had found that the diagrammatic curve worked out for representing the relative diameters was of an astonishing kind, as shown in Fig. 27, Plate 94, and as would be seen from a couple of examples. For a 1½-inch rope a 6-foot pulley was sufficient; but for a 2-inch rope under the same conditions a 12-foot pulley would be required. In Plate 94 the dotted wavy curve had been developed from a mean of two sets of results, one set comprising the tensile strengths of ropes of various diameters, and the other set their resistances to bending; the full fair curve was a symmetrical rendering of the dotted. When large ropes were sometimes seen to be working over dynamo pulleys of perhaps only 18 inches diameter, it was not surprising that arbitration should have to be invoked on the question of how long the ropes ought to last. The number of times per minute that the rope was bent backwards and forwards was the element which determined how long it was going to last. It had sometimes been urged that on board ship, where there were so many ropes going round small blocks, the small diameter of the sheaves in the blocks ought to have a detrimental effect upon the duration of the ropes. So it would have, if the ropes had to be continuously going through the blocks; but as a rule it would be found that the ropes were mostly stationary on the blocks, moving only at occasional intervals; and providing the limit of bending was not passed as regarded the internal structure of the rope, then, even as long as it was moving, it did not sustain much damage from the movement, or from the strain which it received in bending round a sheave. All the different arrangements described in the paper for getting over the difficulties of the angles of the shafts were in his opinion undoubtedly practical, and most useful for everyone who had works in which the driving of machinery had to be arranged. Crossed

(Mr. Benjamin A. Dobson.)

ropes he had seen in use. The largest size of rope he had himself adopted for driving was one inch and a half diameter, and he preferred multiplying the number of ropes and using a smaller diameter, say one inch; some ropes which he had had running fourteen years seemed still as good as when they were put on. The great point was to have the pulleys large enough and the ropes small enough. From his own experience he would recommend never to put on a 2-inch rope. A 1½-inch rope was as large as ought to be required; or if the pulleys could be got large enough, even a 1¾-inch rope might be used. But he had seen several cases in which 2-inch ropes had been an absolute failure.

Mr. Michael Longridge, referring to the size of the ropes used for driving, pointed out that at present in cotton mills the shafts were run at a high speed; 300 revolutions a minute was common, and he knew mills where they were running at 450. For such speeds small pulleys were essential; and where there were small pulleys, there must be small ropes. From this cause he thought an idea had got abroad that smaller ropes were intrinsically and essentially better than larger, which he considered was a mistake. For economy, power, and wear, the largest rope should be used that was compatible with the size of the pulleys. The main point in rope driving was to keep all the ropes of the same size that were running in conjunction upon the same pulleys, so that they might all run at the same speed. If any one rope became reduced in diameter, either by excessive tension or by wear, it sank more deeply into the grooves, and therefore did not run as fast as the rest of the ropes that were less deep in their grooves. The difficulty of keeping a great many ropes to be all of the same size was much greater than the difficulty of keeping a few to the right size. From his own observation he was satisfied that, if large ropes were put on large pulleys, if the strain were kept low, and if the speed were moderate, not exceeding about 4,000 feet per minute, the difficulties sometimes encountered in rope-driving would cease to exist, and the ropes would last for a number of years: in many cases for ten years, and in some instances he had known them last even longer. The use of

English or Irish hemp for ropes had not been mentioned in the paper; he was glad to say it was largely used in Scotland, and with great success.

Mr. JOHN D. BARBOUR, Hilden Flax Mills, Lisburn, said that about thirty years ago his firm had a well-appointed mill driven by gearing, which was believed to be as good a kind of gearing as could be devised; but they had been induced by his brother-in-law, the late Mr. James Combe, to try rope driving, which on trial had been found to answer remarkably well. They were now transmitting he believed about 700 or 800 horse-power by ropes, and found it a highly economical and pleasant mode of driving. He fully concurred in the remarks of previous speakers as to the advantage of moderate speed for the ropes; and he considered 4,000 feet per minute was a good limit of speed (page 368). At their own works his firm had been using ropes of 2 inches diameter, and it was impossible to say how long these would last, because they would probably outlast the lives of every one there; the present ropes had been running for years, and were practically as good as when they were started. Although perhaps few had had more experience than himself in the different methods of driving machinery in mills, for his own part he should much like to know more exactly the power absorbed in the transmission of power by ropes as compared with toothed gearing. In transmitting power through gearing he had found about 30 per cent. was lost in friction, including the friction of the engine; and with ropes it was practically the same. It was the general opinion that ropes absorbed more power than gearing; but that was not the experience of his firm. In America the use of ropes was being departed from, and the power was being transmitted by belts, and this was found an economical way of driving. His firm there had a large mill driven from a fly-wheel of 60 inches face by two distinct double belts, each 30 inches broad, and each composed of two thicknesses of leather sewn one on the top of the other; these together transmitted 700 horse-power, and worked well, and absorbed less power than

(Mr. John D. Barbour.)

gearing. If anything, the friction he believed was less in transmitting power by broad belts than by ropes.

Mr. J. HARTLEY WICKSTEED, Vice-President, noticed that the origin of rope driving, as invented forty years ago by Mr. James Combe, had been in connection with the application of that beautiful invention, the expanding pulley with V shaped sides. It thus appeared that the invention of the expanding pulley had really been the origin of the form of rope driving in which a round rope ran in V grooves. An ancient instance of rope driving had been recalled by Mr. Dobson (page 366), and no doubt other old examples could be found; but he thought not in conjunction with the angular groove, having an angle of about 45°, which had proved so successful a plan for the use of ropes. He could himself fix and confirm with great certainty the date at which the expanding pulley used in conjunction with the round leather rope had been exported from Belfast and imported into Leeds; in reality it was within two years of Mr. Combe's invention of rope driving. Having himself been apprenticed in 1858 to Mr. Joshua Buckton, tool-maker of Leeds, who occasionally made journeys to Belfast and knew Mr. James Combe and had seen his expanding pulley, he remembered his obtaining his permission to fit it up for rope driving to a drilling machine, which was to be shown at an exhibition in Leeds in that year, when Her Majesty came to open their new Town Hall. These facts taken together proved that in 1858, within two years of the application of the expanding pulley by Mr. James Combe, there was a drilling machine in Leeds fitted up with expanding pulleys and driven with a round leather rope.

Mr. ALFRED SAXON suggested that the value of the drawings illustrating the many ingenious ways in which rope driving could be taken advantage of would be enhanced if the direction of the rope driving were shown by arrows, so as to make a distinction between the driving and the driven pulleys. The barring engine shown in Fig. 14, Plate 87, for starting the rope fly-wheel, seemed to him to be rather out of date at the present time, when the use of pauls for barring a heavy wheel round had been superseded by various other worm-wheel arrangements. When going yesterday afternoon through one of the works in Belfast he had noticed a barring engine being made with an ordinary worm-wheel and disengaging gear. Some of the fancy drives with crossed and half-crossed ropes shown in the drawings he thought should be adopted only in extreme cases. Rope-driving in mills, particularly in large cotton-mills, in some of which from 1,000 to 2,000 horse-power was transmitted, he should prefer to be done wherever possible by direct driving from the main pulley to the various line-shafts. For such purposes he agreed with Mr. Dobson (page 368) that 1½-inch ropes were quite as large as was advisable and necessary. Counter rope-driving he had found to absorb a considerable amount of friction; in an instance which had come recently under his notice, the total power transmitted through a counter rope-drive amounted to 210 I.H.P., of which the ropes and shafting took 72½ I.H.P., thus showing 34½ per cent. to be absorbed in friction. In the short description given in page 455 of the Falls Mills, Belfast, belonging to the Ulster Spinning Co., it was stated that rope driving had recently been substituted for toothed gearing. It might well be that gearing made in 1833, with long teeth, with the bearings worn and out of line, out of level, and out of square perhaps in all directions, could be considerably improved; but what was wanted was a comparison of the best modern geared mills, such as those in Lancashire, and the best new rope-driven mills. It was mentioned in the paper (page 362) that, in many instances in which gearing had been replaced by rope driving, the total power required had not been increased. This however had not been the experience universally; there had been bad examples of rope driving, as well as good examples of gearing; and no doubt improvements had been made in both methods.

Mr. W. Ford Smith considered the longevity of a rope or its more rapid destruction, when used for driving over pulleys, was a simple matter. As long as a rope was pulled straight, its fibres were all lying without any unequal strains upon them; but as soon as it was bent round a pulley, the fibres that were at the greatest distance from the centre of the pulley were elongated, while there was a

(Mr. W. Ford Smith.)

tendency to compress those that were nearest; and that sort of action in the bend went on alternating continuously with the straight pull, so that, the greater the number of revolutions per minute, the sooner was the rope destroyed. What was wanted to be provided against was the working of the rope in that way; it could be mitigated only by having the pulleys large enough, and the rope small enough; the smaller the diameter of the rope and the larger that of the pulleys, the more durable would the rope be. The same principle applied to a belt, but in a less trying manner, because a belt was comparatively thin.

Mr. **George Saxon** noticed that nothing had yet been said about the number of strands in the driving rope itself, or about the exact reason why three strands were invariably used. The latter he had recently been able to gather from experience, having formerly been unaware that three strands had any special merit. In connection with a rope-driven power-crane, which was used for lifting heavy weights and had consequently a high tension upon the driving rope, it had been suggested by the foreman that a four-strand rope should be employed for greater strength. On enquiring of the rope-maker whether that would be in order, he expressed his readiness to make a rope with either three or four or any other number of strands, but did not profess to offer an opinion as to one being any better or more suitable than another. It had then been decided to have a four-strand rope and try it, especially as the last three-strand rope had not given satisfaction. It was found that the four-strand rope scarcely lasted six weeks; it quickly got ragged, and was soon in a precarious condition. The reason why the three-strand rope was generally used appeared to be that it had a better grip in the groove, and had consequently less strain upon it, especially as its construction did not necessitate the introduction of a core, which in his opinion formed the weakest part of any rope, whenever it had to be inserted. The four-strand rope had accordingly had to be thrown out; and on going back to the three-strand there had not been the slightest trouble with it since, and he expected it would run out its apportioned time, perhaps eighteen months, or twelve at the least, though it had a great deal of work upon it.

Mr. HENRY McLAREN mentioned that he had first become acquainted with rope driving in 1870, in connection with steam-ploughing tackle, for which a 7–8ths inch manila rope was used, transmitting never less than 40 I.H.P. Instead of this, the paper appeared to give a 1¼-inch rope for transmitting only 5 I.H.P. per 1,000 feet per minute speed of rope (page 357). The ploughing ropes usually lasted twelve months, and then began to give trouble; working during wet weather was highly injurious to them. The portable ploughing engines had two 8½-inch cylinders, running with a piston speed of 450 feet per minute, and 80 lbs. initial steam-pressure; over a hundred sets of those ploughing engines had been constructed. The ropes were 1,600 yards long, and had to be put all round the field to be ploughed; it was therefore highly important that they should be kept light. The manila rope was found to last much better for this work than the cotton; it was a specially long fibre, and was made by Messrs. George Cradock and Co., Wakefield. After the rope began to break, it had to be cut and re-spliced on the ground; and the agricultural labourers became expert at splicing. On one occasion he remembered as many as twenty-four splices having to be made in a day. The pulleys for the 7–8ths inch rope were 20 inches diameter; ropes of larger diameter working over the same pulleys failed much sooner than the 7-8ths inch rope. Temporary pulleys were stuck in the ground all round the field, just like fitting up a mill. It took about half a day to put a rope round 30 or 40 acres; everything depended upon whether the fences were straight or crooked, because corner pulleys had to be put in at all bends. The ropes ran at 3,500 feet per minute; and seeing that with a 7-8ths inch manila rope it was possible to transmit from 40 to 60 I.H.P. at that speed, he considered the sizes of ropes given in the paper for the various powers were excessive. On pulleys of small sizes it would be better he thought to run smaller ropes than many of those that were now employed on small pulleys.

Mr. BRYAN DONKIN, Member of Council, mentioned as a matter of history that in 1868 he had seen at Colmar in Alsace many long steel-wire ropes used for driving shafts in cotton mills, which were

(Mr. Bryan Donkin.)

arranged and designed by C. Frederick Hirn, brother of George A. Hirn. These wire ropes * had first been used in 1852.

Mr. W. Lloyd Wise mentioned, both as a matter of history and also as indicating how different minds were sometimes directed to the same subject, that, before the expanding pulley had been brought out by the late Mr. James Combe, to whom so much credit was due for its introduction, his father, the late Mr. Francis Wise, who had been a Member of this Institution, had really worked the plan out on paper in its complete form; and he believed that somewhere about 1858 or 1859 his father had written to the late Mr. Combe, drawing his attention to this fact as a matter of interest.

Professor John Goodman thought that the large factor of safety employed in rope driving would account to a great extent for the discrepancy between the power transmitted, as given in the paper (page 357), and the power mentioned by Mr. McLaren (page 373). In ordinary rope driving he believed it would be found that the factor of safety was as high as ninety: that is, the working load on the ropes was only about one-ninetieth of their ultimate strength; but the ropes used by Mr. McLaren must have been worked much nearer to their breaking load. Some years ago he had seen an ingenious method of driving, by means of a continuous rope, machinery for charging and drawing the retorts in a gas-works. A long horizontal rope ran from one end to the other of the retort house, and was coiled once round a driving pulley, which made one complete revolution. The difficulty of the chafing of the rope where it entered and left the pulley was avoided by making the pulley taper or conical, so that the diameter on the entering side was greater than that on the leaving side; the rope consequently slipped sideways, so that the leaving span was clear of the entering span.

Mr. A. Basil Wilson had recently had an opportunity of trying four different kinds of ropes. The first kind were manila three-

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* Notice sur la Transmission Télodynamique, par C. F. Hirn; Mulhouse 1867.

stranded. The second were cotton, consisting of an internal core served round with a lapping of small rope $\frac{1}{4}$ inch diameter: so that practically the portion which had to take the pull was of small diameter, while the surface bearing on the pulley was of considerably larger diameter, thereby reducing the strain on the core to a minimum. The third kind were three-stranded cotton ropes; and the fourth four-stranded. These four kinds he had tried simultaneously on four different engines, running them practically against one another. The first point of difficulty was to get a thoroughly good splice; the next in value was the duration of the rope; and the last, the amount of friction absorbed in passing into and out of the pulley grooves. With regard to the splicing, the three-stranded rope made by far the best splice, owing to the fact that the loose strand was nipped between two tight strands. The four-stranded rope did not give so good a splice, as it had to have a core, and the loose end had to be passed between the two tight and the one loose strand. A rope with four strands necessarily required a core; whereas three-stranded ropes did not, and had thereby an advantage, since the core gave no practical strength. The working of the four-stranded and three-stranded ropes was apparently almost identical. They showed no important difference in wear, when they were placed side by side on pulleys of equal diameter, so long as the splices were kept right; this was the point upon which the difficulty occurred. The wear on the lapped rope, which consisted of a small core lapped round with what sailors called "serving," was less than on any of the other three; but here occurred the greatest difficulty in splicing, inasmuch as the outer wearing lapping could not be thoroughly spliced into the heart of the rope. The main point however in the life of a rope was not generally known or considered: namely that, in the ordinary mode of "laying up" a strand in the process of manufacture, it was found that the interior yarns in the strand became buckled by compression, in the absence of any tensile strain upon them while being laid; the outer yarns had therefore to bear the strain of working, while the inner ones were slack; this arose from the fact that the central yarns while being laid ran absolutely straight out of

(Mr. A. Basil Wilson.)

the reels, while the outer ones having to pass round a helical curve puckered up the inner ones. This difficulty had been got over by a modification in the method of laying; and where ropes were thus properly made, all three strands were under equal tension both inside and outside, and the duration was extraordinary. The theoretically effectual rope which would produce least friction would be one having such elasticity that, when the pull came upon it to lift it out of the groove, it would be thereby so reduced in diameter that its grip in the groove would become nil. Ropes which on entering the grooves were somewhat larger in diameter than on leaving would produce but little friction. If on the other hand the rope was of such a rigid nature as to maintain its diameter whether strained or not strained, the friction in the groove was largely increased.

With regard to the relative diameters of the ropes and of the pulleys, present practice had grown up from experience; and it would seem that the rule for the size of rope was entirely dependent on the class of rope to which it was applied. A lapped rope could be used for passing round a pulley of approximately one-third smaller diameter than a three-stranded or a four-stranded rope. A cotton rope, owing to its greater elasticity, could be used with efficiency round a smaller pulley than a manila rope.

A visitor mentioned that fifteen years ago he had employed in India a coir rope made of the fibre from the husk of the cocoa-nut, and it was still working there most satisfactorily.

Mr. Combe pointed out that the diameters of pulleys recorded in the paper as those adopted by Mr. James Combe for the various sizes of ropes were the minimum diameters, not necessarily the proper diameters for all classes of work (page 367).

In regard to the half-cross drives (page 364), Plates 89 and 93, the reason for having the ropes arranged in the way shown in Plate 93 was that the pulleys were so close together that single ropes would be too short. In these half-cross drives the driven pulley was placed in the same plane as the axis of the driving pulley, so that the ropes entered and left the grooves at approximately the same angle to the plane of the groove, in order that the amount of friction between the rope and the edges of the groove should not be excessive either when entering or when leaving the groove, as it would be if the pulleys were placed in the relative positions usually adopted for strap driving. What had been termed fancy driving (page 371) he did not recommend, when straightforward driving would do. The special drives which had been brought out from time to time had been due to particular circumstances: difficulties had had to be overcome, and they had been overcome by these fancy drives; but where straightforward drives would do, they were used.

It was true there was a large margin of safety in rope driving (pages 373 and 374), in so far as the strength of the rope itself was concerned; but it was not so much the strength of the rope that had to be taken into account, as the fact that slip of the rope in the groove must be avoided. In Ireland mills could not afford to stop twenty-four times in a day for splicing the ropes, as in steam-ploughing. Experience had shown that if a sufficient number of ropes were employed, so as to keep the power transmitted by each down to the bases given in the paper, they would last fifteen or twenty years without trouble. The object of the paper had been to deal with rope driving as introduced and developed for driving mills and factories by such arrangements as were illustrated in the drawings, with several ropes working side by side; and he had not taken into account the driving of individual machines, such as drilling machines (page 370) or travelling cranes (page 365) or spindles, nor the use of wire ropes in Switzerland (page 373), which formed an entirely different class of rope driving.

The barring engine with pauls, shown in Fig. 14, Plate 87, belonged to the original fly-wheel specially designed for rope driving in 1879, and had therefore been copied from the old drawing shown in Fig. 10, Plate 85. At the Falls Foundry he should be happy to show how good barring was now done by modern appliances (page 370).

For showing the direction of running, no arrows were necessary on the drawings, because the direction of driving was either forwards or backwards as desired. There were frequent examples of ropes working at quite as great obliquity as shown in the drawings; in

(Mr. Combe.)

some the ropes entered on the same side as here shown, and in others on the other side.

With regard to the power transmitted by the several sizes of ropes and pulleys tabulated in page 357, it was not meant that they should always run at 100 revolutions per minute; the power was simply given per 100 revolutions as a convenient basis for calculation.

The kind of splice that had been found best for rope driving was what sailors called a "long" splice, say from six to twelve feet long; and not only were the strands cut at different points, but subdivisions of the strands were also made and cut at different places, so as to spread the joints over a number of intervals, whereby the part of the rope where the splice came was made no larger in diameter than the remainder of the rope.

The PRESIDENT proposed a cordial vote of thanks to Mr. Combe for his valuable paper, which had been so highly appreciated by the Members, and had given rise to so interesting a discussion.

Mr. E. H. ELSWORTHY wrote that from his own experience in India he should much have doubted whether coir or cocoa-nut fibre ropes (page 376) would give any good results. The fibre was hard, coarse, and of a short staple; and there would be great difficulty in making a suitable long splice. It was also much affected by climatic changes, and if allowed to get damp would contract so much as to render it liable to break, if it had been sufficiently tight on the pulleys when dry. They might be put on as a make-shift, if no others were available; but he had never heard of their being used in any works as a permanency.

Mr. DRUITT HALPIN wrote that he considered the loss in transmission by belts and ropes was still a most important subject, the determination of which he hoped would soon be undertaken in a comprehensive and suitable way. In the discussion of Professor

Capper's paper on the Lille rope and belt experiments (Proceedings 1895, page 640) he had suggested that the power absorbed might be determined by the employment of dynamometer springs; and it had since occurred to him that a simple and practically perfect instrument of this kind might be produced if the arrangement for measurement described in Mr. Towne's paper on Emery's testing machine (Proceedings 1888, page 206) was used, in which the loads were measured by discs capable of very accurate calibration.

DESCRIPTION OF THE ALUMINA FACTORY AT LARNE HARBOUR.

By Mr. JAMES SUTHERLAND, Manager.

Sources of Aluminium.—Aluminium is one of the most abundant metals found in the earth. In the metallic state it is not met with; but its compounds with oxygen, fluorine, the alkalis, silicon, and the acids are so numerous and so widely diffused that it is almost impossible to obtain a portion of the earth's crust in which it will not be found. The compounds of aluminium with silicon and other bases are the most numerous. These in the form of felspar and mica, mixed with quartz, form granite. By the influence of air and water these compounds are decomposed, the alkali is replaced or carried away, and the residues form clays. Such precious stones as the ruby, sapphire, garnet, and cryolite, also contain large quantities of the metal; the ruby and sapphire are almost pure oxide, or alumina; and cryolite, a double fluoride of aluminium and sodium, is found in abundance, containing 13 per cent. of aluminium. But the clays present the largest source of the metal; and the mineral called Bauxite is generally used for its production. Bauxite derives its name from the French town of Beaux, near which it was first discovered. Since that time large deposits have been found in County Antrim, where thousands of tons have been mined during the past twenty years, chiefly for the manufacture of sulphate of alumina and other salts of aluminium.

Analysis of Bauxite.—County Antrim bauxite contains:—alumina 56 per cent., corresponding with aluminium 29·9 per cent.; peroxide of iron 3; silica 12; titanic acid 3; and water 26 per cent. From this analysis it will be seen that, if the aluminium is to be obtained in a state of purity, the peroxide of iron, the silica, and the titanic acid must be separated out before the extraction of the metal from the alumina is attempted.

Alumina Factory.—The most convenient method for obtaining pure alumina from bauxite is that discovered by Dr. K. J. Bayer, which is used in the Alumina Factory at Larne Harbour. The factory is situated close to the terminus of the narrow or 3-ft. gauge line of the Belfast and Northern Counties Railway, whereby it is conveniently connected with the mines at Glenravel, 35 miles distant. As shown in the plans, Plates 95 and 96, the main building of the factory is 240 feet long and 80 feet broad, the loftiest portion being 30 feet high; it is built of brick, and covered with a slated roof on iron principals, in two bays of 40 feet span each. Steam at 100 lbs. pressure per square inch is generated in two Lancashire boilers, 25 feet long and 8 feet diameter, fed by a direct double-acting duplex steam-pump, with pure water at 180° Fahr. obtained from the evaporating apparatus. The necessary draught is obtained by a chimney 120 feet high. The driving power required is supplied by a horizontal non-condensing engine, with cylinder 14 inches diameter and 20 inches stroke, running at 140 revolutions per minute. The slide-valve has an expansion valve on the back, and the cut-off is regulated by a hand-wheel. The engine is capable of exerting 80 horse-power when working against a back pressure of 10 lbs. This amount of back pressure is due to the exhaust steam assisting in the heating of the evaporating apparatus. The power is transmitted to the main shaft, which runs at 200 revolutions per minute, by four 5½-inch cotton ropes driving on the fly-wheel, which is grooved for the purpose.

Grinding and Calcining.—The trucks of bauxite as received from the mines are run directly into the grinding room. Here the ore is fed into a disintegrator, and ground to ¼-inch cubes, which fall down a shoot into the bottom boot of an elevator, whereby they are delivered into a riddle of ¼-inch mesh. The ore which passes through the mesh descends a sheet-iron pipe into the calciner; while the tailings are returned to the disintegrator by gravitation, to be ground over again. The organic matters present in the ore require to be destroyed, and for this purpose calcination is resorted to. The calcination is important, because the presence of organic matters would retard, if not totally prevent, the subsequent separation of the alumina from the caustic soda in the decomposing cylinders. On the other hand, too great heat would cause the ore to become far less soluble in the solution of caustic soda.

Calciner.—The calciner, shown in Plate 97, consists of an iron tube C, 33 feet long and 3¼ feet diameter, lined with fire-brick, and mounted on rollers to permit of its revolving. It is inclined at an angle of 1 in 25, and is heated by a furnace at the lower end, from which the heat passes up through the tube and into a chimney at the higher end. As the tube revolves, the bauxite fed into the higher end travels downhill towards the lower end and meets the heat ascending from the furnace, which is regulated to suit the extent of calcination required. On leaving the tube the calcined ore falls upon a plate P having a slot in it just large enough to allow the bauxite to pass. Through the slot it descends by a shoot into the cooling tube L, which is 30 feet long by 2½ feet diameter and also revolves, being inclined in the opposite way to the calciner tube. Here the ore is cooled by a current of air drawn through the tube by a fan connected with the opening F. At the outfall of the cooling tube is placed a spiral conveyor S, which discharges the ore into a second disintegrator, where it is ground sufficiently fine to pass through a 30-mesh sieve, that is, one with 30 holes per lineal inch, or 900 per square inch. Thence an elevator deposits it in a store having a hopper bottom, underneath which the small trucks can be run to be filled.

Kiers.—The alumina is extracted from the ground bauxite by treating it with a strong solution of caustic soda under steam-pressure. A soluble compound of alumina and soda, called aluminate of soda, is thereby formed, while the peroxide of iron, silica, and titanic acid remain as insoluble compounds. This decomposition is effected in pressure kiers, shown in Plate 98, which are constructed of mild steel plates $\frac{5}{8}$ inch thick, and are 11 feet long by 5 feet diameter inside, and surrounded with a steam-jacket for heating. A horizontal 3-inch shaft runs through the kier longitudinally, and is fitted with eight 16 × 9-inch paddles, which keep the contents in constant agitation. Stuffing-boxes are fitted at the ends of the kier, for the shaft to run in. Each kier is provided with a charging opening C, a discharging opening D, and a safety-valve V; and the jacket with steam inlet, safety-valve, and water outlet, the latter being connected with a steam trap. The kiers have been tested to 200 lbs. per square inch, and are constructed to work at 100 lbs., although in practice about 80 lbs. is found to be sufficient for effecting the decomposition of the bauxite.

The necessary supply of caustic soda solution having been run in, usually of 1·45 specific gravity, the agitator is set going, and the bauxite previously weighed is admitted. This is done by a small elevator, which supplies the quantity automatically and regularly, thus ensuring thorough admixture. When the charge is all filled in, usually about 3 tons, the charging opening C is closed, and steam is turned on into the jacket. The pressure is slowly increased up to 70 or 80 lbs., which is maintained for two or three hours, until the decomposition is complete. The discharge cock D is then opened, and the mass is blown out by the pressure in the kiers up into the red-mud tanks, which are placed in the highest part of the building. Here the mass is diluted with washing water to a specific gravity of 1·23, and is then ready to be filtered in order to separate out the aluminate of soda solution from the impurities.

Filter Presses.—The filter presses used for this purpose each contain fifty chambers, giving cakes 30 inches square and 1 inch thick. The impurities being insoluble are retained in the press, while the liquid aluminate runs out into the filter tanks. When the press has become filled with red mud, the cakes before being removed from it are subjected to a systematic washing, for extracting as much of the aluminate of soda as possible. The washing water is utilized for diluting the mass blown up from the kiers. Centrifugal pumps are employed for charging and washing the presses. Conveyors are placed beneath each filter press, which receive the cakes of red mud when the press is opened, and deposit them on trucks placed outside the building. At present the red mud is useless, but experiments are being conducted, which it is hoped will result in a profitable use being found for what would otherwise be a troublesome by-product.

Cellulose Filters.—The lyes from the filter-presses, collected in the filter tank, are then subjected to another filtering process through cellulose consisting of paper-makers' wood pulp. These filters are composed of lead-lined vats with sloping sides, 10 feet long by 6 feet broad and 3 feet deep, with a ledge round the inside 6 inches from the bottom, on which is placed a sieve of 1–8th inch mesh, supported on a frame. Two of these filters form a set, one placed above the other. About 50 lbs. of cellulose is boiled with water to a thin pulp, and is run upon the sieve in each filter; it soon settles down, and is ready to receive the lyes, from which it retains all the finely divided insoluble particles that have escaped from the filter presses; the result is a perfectly clean liquid composed of pure aluminate of soda. This final filtration is necessary if the alumina, and consequently the aluminium, is to be produced in a state of purity.

Decomposing Cylinders.—For the separation of the alumina from the soda, the decomposition of the aluminate was formerly effected by blowing carbonic acid gas through the liquor, when the soda combined with the carbonic acid, forming carbonate of soda, and the alumina was set free in the form of hydrate of alumina. The carbonate of soda had afterwards to be re-transformed by a chemical process into caustic soda, before it could again be used for decomposing a fresh charge of bauxite. By the Bayer process the separation of the hydrate of alumina is brought about by the addition of excess of hydrate of alumina itself, and constant stirring in the decomposing cylinders, which are large circular tanks 13 feet diameter and 20 feet high, provided with agitators. In practice the liquid aluminate of soda from the cellulose filters is pumped up into large tanks of 4,800 gallons capacity, placed above the decomposers. The liquor can be measured and heated, if necessary, in the tanks. The decomposer, in which sufficient hydrate of alumina has been allowed to remain for beginning the decomposition, is filled, and the agitation started. In about thirty-six hours, 70 per cent. of the alumina in combination with the soda has separated out; and this is the extent to which the precipitation usually takes place. The agitator is then stopped, and the contents of the decomposing cylinder are allowed to settle. In a short time the hydrate of alumina settles to the bottom, and the clear liquor is run off the top by gravitation into the weak-liquor tanks.

Hydrate Filter-Presses.—After as much as possible of the clear liquor has thus been decanted off, the hydrate of alumina is pumped out of the decomposing cylinder, sufficient being allowed to remain behind in the cylinder for beginning the decomposition of the next charge of liquor admitted. The hydrate of alumina pumped out is filtered through filter presses, and the weak liquor passing through the cloth is allowed to run into the weak-liquor tanks. The charging of the hydrate filter-presses is done by a horizontal twin direct-acting steam-pump, with steam cylinders 7 inches diameter, rams 5 inches diameter, and 12 inches stroke. The pump is provided with an automatic arrangement for shutting off the steam when the presses are full: a ½-inch pipe leads from the air vessel, and when the pressure exceeds 80 lbs. it raises a weighted diaphragm, which closes a valve placed in the steam-pipe beneath the throttle-valve, and so cuts off the steam.

Washing and Drying.—When the filter presses are full, washing is commenced, in order to remove the last traces of soda. The pump for this purpose is duplex direct double-acting, with 5¼-inch steam cylinders, 3½-inch pump cylinders, and 5 inches stroke. The washing is done systematically as before, in five different stages, the last of which is with pure water. After washing, compressed air is forced through the cakes to remove as much water as possible. The air compressor is horizontal, with steam cylinder 8 inches diameter, air cylinder 6 inches diameter, and stroke 14 inches. It has a suction capacity of 90 cubic feet per minute when running at 120 revolutions per minute and delivering at 80 lbs. pressure per square inch. The air-compressing cylinders are provided with water-jackets to keep them cool.

Calcining Furnace.—Conveyors are placed beneath the hydrate presses, which deposit the hydrate of alumina on the top of the calcining furnace, where the moisture and water of hydration are driven off. The furnace has a bed 20 feet long and 6 feet wide, and is fired with Dowson gas, for which the generator is placed in a small shed outside the main building, so that no dust may get mixed with the alumina. The products of combustion pass between the arch over the hearth and a drying tray placed above, on which the hydrate gets a preliminary drying before being admitted to the hearth. A low temperature is sufficient to drive off the moisture and the water in chemical combination, leaving the alumina perfectly anhydrous; but if formed in this way it takes up water again readily. To prevent it from doing so, the anhydrous alumina is heated to about 2,000° Fahr., when it becomes crystalline, in which state it is not so liable to absorb moisture. It is important to have the alumina as dry as possible, for the presence of water means a corresponding loss of electricity during the subsequent reduction. When the calcination is complete, the alumina is drawn into iron barrows, and spread on a tiled floor to cool; after which it is ready to be packed in casks.

Evaporator.—The weak soda liquors from the décomposers and hydrate presses, having a specific gravity of only 1·2, are too dilute to dissolve the alumina out of the bauxite, and must therefore be concentrated by evaporation up to 1·45 specific gravity. The evaporator is of the triple-effect kind, and is capable of evaporating 33,000 gallons of water in twenty-four hours. It has independent feed, air, and circulating pumps; and the exhaust steam from these, as well as that from the main driving engine, assists in heating the evaporating pans. The circulating water is discharged into a small concrete tank or pond, whence it is pumped up by a 5-inch centrifugal pump to the top of the cooling tower, which is 30 feet long, 20 feet wide, and 25 feet high, and is provided with four trays. During its descent into the pond the water is reduced 40° in temperature, namely from 100° down to 60° Fahr. The water evaporated from the weak soda liquors being pure, and having a temperature of 180° Fahr., is used for washing the hydrate of alumina, and for boiler feeding, &c. It is stored in a lead-lined wooden tank of 6,000 gallons capacity, placed above the decomposers; the supply for the hydrate washing is filtered through a small cellulose filter placed beneath. All the drainage of the factory is collected in a concrete tank placed in the yard, and is pumped back, to be used for washing the red mud, dissolving soda, &c. Any soda, aluminate of soda, or water, which escapes by leakage or otherwise from any of the processes, is thus saved. The pump for this purpose is similar in size and make to the boiler feed-pump; it is placed in the boiler house, and is arranged to feed the boilers in case of a breakdown of the feed-pump proper.

Electric Lighting.—A 15-unit Taunton dynamo is used for lighting the factory at night by means of ten arc lamps of 2,000 candle-power each and one hundred incandescent lamps of 16 and 32 candle-power. The dynamo is driven by a Robey vertical steam-engine, from which the power is transmitted by four cotton ropes of one inch diameter. The dynamo and engine are self-oiling, and require very little attention.

Extensions.—Provision has been made for extensions, the buildings being capable of containing double the machinery already erected; and the beams and columns are already in position for receiving the additional apparatus which, it is hoped, an increasing demand will soon render necessary.

Discussion.

Mr. Sutherland exhibited a set of specimens exemplifying the successive stages of the manufacture, from the crude bauxite to the finished alumina. The collection comprised broken stones of bauxite as received from the Glenravel mines; ground $\frac{1}{4}$-inch cubes of bauxite from the disintegrator and riddle; calcined bauxite of the same size, and afterwards ground and sieved through a mesh with 30 holes per lineal inch; red mud from the kiers; the lyes or filtered aluminate from the filter presses, and the cleared aluminate from the cellulose filters; hydrate of alumina from the decomposing cylinders, and again after filtration through the filter presses, and again after washing and drying; and calcined alumina in its final crystalline form.

Mr. Benjamin A. Dobson, Member of Council, asked whether any information could be given respecting the commercial result, namely as to the ultimate cost of producing metallic aluminium, by this preliminary process of preparing the pure alumina in the manner described in the paper, and by the subsequent reduction of the metal from its oxide by electricity. Aluminium itself was becoming every day more and more valuable to engineers. In whatever form it was used, whether in steel and iron as increasing the fluidity and homogeneity of the metal, or whether in mechanical construction, there could be no doubt that its importance was daily increasing; and engineers, however scientific they might be, had a commercial side to their business, and liked to get their materials as cheaply as possible.

Mr. Sutherland explained that the operations carried on in the factory at Larne Harbour terminated with the production of the calcined alumina, and did not include the reduction of aluminium from its oxide. The first object was to extract from the ore pure alumina; and the process of doing so was all that had been described in the present paper. The electric reduction of metallic aluminium from the pure alumina manufactured at Larne was performed in the factory of the British Aluminium Co. at Foyers near Inverness, where it had not yet been carried on long enough for enabling the details of the process to be described. A subsequent paper however he believed would be given to the Institution in due course upon the works at Foyers, for showing what had been done there.

The PRESIDENT proposed a vote of thanks to Mr. Sutherland for his paper and the specimens he had brought, which would together enhance the interest of the visit the Members would make under his guidance tomorrow afternoon to the Alumina Factory.

DESCRIPTION OF THE BELFAST GAS WORKS.

By Mr. JAMES STELFOX, Engineer and Manager.

Historical.—The Gas Industry may be said to date from the early years of the present century, though numerous records prove that private establishments were lighted by means of coal gas at a considerably earlier period. The first public lighting of London by gas was witnessed in 1813 on Westminster Bridge; and within the next few years a rapid extension of the plan took place, not only in the metropolis but also throughout the country. In Belfast, notwithstanding its remoteness at that period as regards time and convenience of transit from those manufacturing centres which seem chiefly to have excited the enterprise of the pioneers in gas engineering, the subject received attention as far back as 1817, when the original projectors of the gas works appear to have been represented by Mr. E. Spear, with Messrs. Barlow Brothers as engineers and architects for the undertaking. About 1821 a start was made on a little plot of land on the Ormeau Road, A B C D E F G in Plate 99, the site being now occupied by a portion of the present offices and by the retort house &c. of the old section of the works. The contract for laying the necessary pipes and services was given to Mr. Charles Burt Robinson of London, whose name was afterwards well known in connection with the gas undertakings of Leicester, Coventry, and Leamington, and with the gas industry generally. The works were first brought into use in the autumn of 1823, and in the "Belfast News Letter" of 2nd September of that year appeared a long and interesting account of the new undertaking.

The works stood well out of the town of that date, and covered an area of about 1½ acre, having a frontage to Ormeau Road of

220 feet and a depth of about 300 feet. The retort house was 100 fee long by 36 feet wide, and contained forty-five cast-iron retorts, from which the possible make could not have exceeded 100,000 cubic feet per day, while the actual production was probably not nearly so much even in midwinter. The purifiers seem to have been boxes 4 feet square, and the station meter passed 50 cubic feet per revolution. The largest of the six meters now in use is capable of passing 57 times that quantity. There were three gas-holders, each 40 feet diameter, 15 feet deep, and containing 18,500 cubic feet each, or 55,000 cubic feet in all; the latter amount may be taken as fully equal to the largest day's consumption. During last winter the largest day's consumption was about 133 times as much, amounting to 7½ million cubic feet.

A great impression seems to have been produced by the method of building the chimney, as well as by what was considered its great height, namely 97 feet. An old doggerel ballad, which was sung in the streets shortly after the inauguration of the works, truthfully refers to "the great Robert Hall, who built the gas chimney without scaffold at all."

An unprofitable period of difficulties was happily terminated in 1852, when the management was entrusted to the writer's father, to whose patience, perseverance, and energy it is due that the concern was rescued from the quagmire of financial failure, and placed on so sound a foundation that when it was purchased in 1874 for the community the operations were being so carried on as to render the transfer a great public benefit.

Extensions.—In 1852 the gasholder accommodation began to prove insufficient, the full storage being about 290,000 and the maximum day's consumption about 430,000 cubic feet; and within a month of the new manager's appointment he was called upon to undertake an extension in this direction, which was carried out during the following year. The new gasholder, at that time considered colossal, No. 3 in Plate 99, was 100 feet in diameter, rising to a height of 50 feet, and containing when full about 380,000 cubic feet, which is equal to about twenty-five minutes' supply during the period of present maximum consumption. It is still at work, and rendering excellent service. The producing and purifying plant next became too small, so that extended retort houses and purifiers had to be provided. As regards the former, after utilizing an old coal shed as a retort house and tinkering up the old benches, it was thought desirable to build an entirely new house over the top of existing benches, and to cover new ground for further expansion in this department. The obligation to keep things going rendered it necessary however to follow the lines of the old house, a necessity which has resulted in great inconvenience of working. A set of purifiers each 10 feet square had been added, but served only for a short time to stave off trouble; and therefore it was resolved to add another set of 12 feet boxes, which it was then supposed would meet all requirements. By 1861 the daily output had reached a maximum of over a million cubic feet, and storage had again become insufficient. It was accordingly resolved to put up a still larger gasholder, No. 1 in Plate 99, 110 feet diameter, rising 52 feet, and holding when full about 560,000 cubic feet, which was placed on the space occupied by four of the six small holders; and the tanks of the remaining two were converted into tar and liquor wells. While this work was being carried out, an accident occurred which momentarily jeopardized the supply of gas to the town for the whole winter. The wall of the new tank fell in, carrying with it the wall of the neighbouring tank and the gasholder as well. Fortunately the community were spared from the threatened catastrophe, and the two tanks were rebuilt, the one which was replaced, No. 2 in Plate 99, being made larger than the original: so that by the following year the storage for gas had been increased to about 1,350,000 cubic feet, the daily maximum being nearly 1,250,000 cubic feet.

Coal Supply.—Up till 1865 all the coal used in the works had been carted from vessels at the quay, and the low cartage rate of only 7*d.* per ton gave no inducement for a change. Gradually however coal vessels had to discharge at a greater distance from the works, and wages and other charges began to increase, causing the cost of cartage to rise from time to time until it reached 1*s.* 2*d.* per ton. All coal was then received into barges and brought alongside the gas-works wharf, where it was discharged as before by means of bags, which were carried from the barges to carts and from the carts into the retort houses and stores. To facilitate delivery the retort houses were placed as near the front gate as possible: a somewhat undesirable arrangement, which would not have been adopted if it could in any way have been avoided. The cost of transit from the wharf was 8*d.* per ton, and the lighterage 5*d.*; so that a saving was effected, but only to the trifling extent of 1*d.* per ton. The congestion caused by the constant stream of coal carts entering and leaving the gate, and impeding the vehicles coming for coke or bringing lime &c. into the works, became each year more serious, and showed that the time was near when it would be impossible in this way to bring into the premises sufficient coal for a day's working.

Elevated Railway, and Cranes.—Meanwhile another gasholder was erected of 150 feet diameter, No. 4 in Plate 99, which when fully elevated contained upwards of one million cubic feet; and a still larger one, No. 5, capable of holding 1½ million cubic feet, was completed in 1874. Two years later the first attempt was made to deal with the congestion consequent on the coal delivery, by the establishment of an elevated platform and railway served by hydraulic cranes at the wharf, which was reconstructed. The rails were carried into every division of the retort houses; and by means of a hoist the wagons were elevated to a still higher level of rails running through the roofs of existing coal sheds. The trouble experienced in carrying out this work was great, and the cost about £6,000, while the saving effected was only about 2*d.* per ton. Its real usefulness however lay in doing away with all the former bustle in the yard, when the utmost that could be taken in per day was only 240 tons; whereas now 700 tons can be taken in with ease, working only one crane, and the yard is freed from this source of congestion.

Stoking Machinery.—In 1884 it was decided to make a trial of stoking machinery in the retort house. The buildings were unsuitable for machines, on account both of their narrowness and of want of length; and in one division only has it been found practicable to work the plan, which is that of Mr. John West, of Manchester. The coal is broken into small pieces in the coal shed, and elevated on to a high-level band, whereon it is conveyed to hoppers situated at the end of the retort house, and from these the charging machines are fed. The machinery is actuated by compressed air at a pressure of about 70 lbs. per square inch. Similar machines of improved make have been provided in the retort house not yet in use; these will be worked by ropes, the power being obtained from engines placed near the end of the house.

Hydraulic Power.—With the advent of hydraulic power numerous appliances were rendered desirable and practicable. Capstans for coal and coke haulage, lifts for covers of purifiers, cranes for coke storage, and small hoists for various purposes have been put up, all of which are worked by water power supplied by a small steam engine having a pair of cylinders of 14 inches diameter and 12 inches stroke. The steam pressure is 40 lbs. per square inch, and the hydraulic pressure 700 lbs. Two accumulators are in use; one of 8 inches diameter with 11 feet rise, and one of 12 inches diameter with 15 feet rise. The increased appliances were at once called upon to meet increased and increasing demands. The consumption of gas had risen from 416 million cubic feet in 1874 to 562 million in 1881; and the addition of still another gasholder of 190 feet diameter, No. 6 in Plate 99, with a rise of 90 feet and a capacity of 2,400,000 cubic feet, brought up the total storage capacity to six million cubic feet. Gradually too the new retort houses were brought into use, until this reserve became part of the daily working in winter, and no margin remained for emergency. The rush of gas was so great that the purifiers were at times quite overpowered, and blew their water seals, causing serious loss of gas and great risk; for on one occasion at least the escaping gas ignited, and but for the prompt action of the foreman there might have been a serious calamity.

Overhead Purifiers.—Every addition of buildings or apparatus in order to produce more gas meant the occupation of valuable space. If the land question seems to have been always a burning one in Ireland, it has certainly been so in the later history of the Belfast Gas Works. As the space originally intended for purifiers was the only ground on which a retort house could be built, in 1891 a new structure with most modern settings and appliances was commenced thereon, and is now ready for work; but other appliances about to be described have thus far prevented it from being brought into use. It forms practically a third complete section of the works, being provided with a full complement of condensers, exhausters, &c. To make up for the loss of ground intended for purifiers it became evident that there was only one way out of the difficulty, and that was upward. Accordingly a set of overhead purifiers has been designed and erected, Plate 100. The structure is mainly of steel, of which some 1,200 tons were used. The upper floor, which is 150 feet by 120 feet, is reached by means of two hydraulic elevators, and will afford storage for upwards of 2,000 tons of lime when trimmed to a height of 3½ feet. The lime is taken up and slaked on the upper floor, and when properly prepared is discharged through apertures in the floor by means of canvas hose-pipes about 10 inches diameter. This method of distributing lime has been used successfully for years past in Glasgow and elsewhere. When it is necessary to change the purifying material, that which is spent is discharged to the ground level through apertures in the bottoms of the purifiers. This work has been carried out in a highly efficient manner by the contractors, Messrs. Hanna, Donald, and Wilson, of Paisley.

Pipes and Crossings.—In bringing up the establishment to its present producing power, it will be readily understood that the connections both over and under ground formed no small part of the difficulties to be overcome. The pipes were becoming not only more numerous, but larger also; the former connections, of which the largest did not exceed 12 inches diameter, had to be replaced by sizes increasing from 18 up to 36 inches. The lines too had to cross frequently, necessitating great depth of excavations and of mains, and rendering the draining of the latter difficult. About 1865, when a problem of special difficulty presented itself, the writer was fortunate enough to hit upon a simple plan for accomplishing the desired end. Fig. 3, Plate 101, shows in plan the position of the scrubbers, and the method of their connection with the main. While the inlet pipe is connected in the ordinary way to the scrubbers, it will be observed that the outlets from the latter pass into a box of square section, Fig. 4, which surrounds the inlet; and it is from this box that the main outlet issues. So useful did this method prove, that advantage was soon taken of it in a modified form for the crossing of existing mains, by constructing a crossing box in halves' as shown in Plate 102, with flanges set at an angle from the horizontal line, so as to afford room for the inlet and outlet sockets, and for a drip outlet at bottom. The latest of these crossing boxes have been fixed in the connections from the water-gas extension, which have thereby been rendered comparatively simple.

Water-Gas.—All these extensions and schemings however would have availed but little, had not an invention been fortunately met with some four years ago, which is due to the ingenuity and ability of American gas engineers. The making of water-gas, carburetted with liquid hydrocarbons, was attempted as much as fifty years ago, but without success; at that time the bulk of the hydrocarbons never got beyond the vapour stage, and on cooling the gas they promptly resumed the liquid form. Various processes were tried without success; and indeed with coal plentiful and cheap, and labour moderate, there was no idea in this country of carburetted water-gas as a possible competitor of coal gas. Different conditions however prevailed in the United States, where coal was dear and labour expensive, while crude oils and naphtha were to be had at low rates. Naturally therefore the gas engineers turned their attention to the manufacture of water-gas, and its enrichment by means of petroleum distillates. Many of the earlier devices were clumsy and unsatisfactory; but the result of years of experimental work was the modern Lowe system. Knowing that this system would at least produce a large quantity of gas on a small space, and would furnish an outlet for coke instead of producing more, the writer four years ago consulted Messrs. Humphreys and Glasgow; and, the project being warmly supported by the then chairman of the gas committee, Mr. C. C. Connor, an order was given them for an apparatus equal to the production of 1½ million cubic feet per day. This apparatus, shown in Plate 103, was set to work at Christmas 1893, and has been in constant daily use from that date. It is remarkable alike for its great simplicity, and for its large efficiency. Gas-making can be stopped at any moment, and resumed at a minute's notice; and a set which has been lying off for some days can be turned into full work in half an hour; while a set which has been so long out of work as to have become quite cold can easily be set going in three to four hours. Into the first vessel G, known as the generator, coke is piled to a working depth of 6 to 7 feet, and being ignited is brought to a high temperature by means of a powerful blast. The products, consisting of carbonic oxide and carbonic acid in varying proportions, together with the nitrogen of the air, pass into the second vessel C, known as the carburetter. At the entrance to this vessel, secondary air is admitted, which effects the partial or complete combustion, as may be desired, of the carbonic oxide into carbonic acid. The resultant gases pass on into the superheater S, at the entrance to which secondary air is again available, in order that complete combustion of the carbonic oxide may be effected here, if it has not already been accomplished in the carburetter. The final products escape into the atmosphere by means of the stack valve, which is left open. This portion of the process is known as "blowing," and its object is to get up the heat, firstly in the generator, so as to secure the breaking up of the steam in the succeeding operation of gas-making or "running," and secondly in the carburetter and superheater, so as to effect the proper "cracking" or gasification of the oil. These two vessels are filled with chequer work of fire-bricks so laid as to baffle the gases in their progress; the spaces left between the bricks are about 2 inches wide. By the spent heat of the generator and the combustion of the carbonic oxide this brickwork becomes heated;

and when the temperature reaches about 1,700° Fahr. gas-making or "running" may commence. For this purpose the blast is now shut off, steam of about 100 lbs. pressure is turned on into the generator, and the stack valve is closed down. The steam follows the same course as the blast, and in its passage through the hot coke it gives up its oxygen to form carbonic oxide, whereby the hydrogen is liberated; and there is thus delivered into the carburetter a gas consisting theoretically of equal volumes of carbonic oxide and hydrogen, which has no illuminating value, but a high heating power. On its entrance into the carburetter, a douche of petroleum oil is sprayed upon hot iron bars placed over the brick chequer work. This oil is preferably heated beforehand by being passed through a delivery pipe which is carried through the main outlet of hot gas. It is at once vaporized and picked up by the non-illuminating water-gas; and in its passage the mixture comes in contact with the hot chequer work, whereby the complete "cracking" or gasification of the oil is effected, which is the sole purpose of the carburetter and superheater. Passing through the main outlet, which is sealed in water so as to prevent any return of the gas, the carburetted water-gas is led on into the ordinary cooling and purifying apparatus, to be there treated in the same way as ordinary gas. The process of "running" is necessarily one of cooling also; and if it were continued too long, the coke in the generator would become too cool to break up the steam, and the surface of the brick chequer work would grow too cold to effect the "cracking" of the oil. Therefore when gas-making has gone on for about seven minutes, the steam is shut off, the stack valve opened, and blowing is resumed for about four minutes, by which time the normal heat in the three vessels is restored, and another spell of "running" commences. After four "runs" have been made, the generator requires replenishing with a supply of coke, which can be fed in through the charging hole at top in about half a minute; and about once in every twelve hours it requires clinkering, a warm and unpleasant operation, which however occupies only about a quarter to half an hour.

Advantages of Water-Gas.—In addition to the ease with which water-gas apparatus can be put into or out of action, there are other advantages arising from its use, among which may be specially mentioned the following.

Economy of Space.—The ground occupied by the water-gas apparatus need not be more than one-eighth of that required for retort houses capable of producing an equal supply of coal gas; and the oil storage tanks occupy about one-fifteenth of the area which would be required for an equivalent coal storage, assuming the coal to be piled up to a height of fifteen feet.

Economy in Outlay.—The cost of water-gas apparatus would hardly exceed one half of that required for coal-gas works, while the charges for maintenance and repairs are comparatively trifling.

Ease in dealing with raw material.—By means of steamers' pumps, 2,000 tons of oil can be pumped into the storage tanks in 36 hours, through two miles of 6-inch pipes. For gas-making this is the equivalent of 20,000 tons of coal, which would be equal to the cargoes of fifty ordinary steam-colliers. The labour involved in transferring this quantity of coal into barges, carrying it to the works, and distributing it in the retort houses and stores, will be readily appreciated.

Effect on Residuals.—The water-gas system gives control as regards the production of coke, and also provides profitable use for a portion of that which is made in the ordinary way. It is possible indeed to arrange such a balance of the two systems as would leave no coke for sale; but it is not likely that such a method of working would be wise or profitable.

Rapidity of Production.—The water-gas is made in immense volume, and from hour to hour can be relied on to undergo but trifling variation as to quantity or quality. When making gas of 24 to 26 candle-power, each run of seven minutes produces about 9,000 cubic feet; so that one set of apparatus is capable of yielding over 900,000 cubic feet in 24 hours. During the past season one set has produced on several occasions a million cubic feet in 24 hours.

Labour Saving.—The economy in this respect is great. Each operator will produce in an eight-hour shift upwards of 300,000 cubic feet of water-gas, whereas the make of coal gas rarely exceeds 18,000 cubic feet per man.

Cost of Gas Production.—At present it is difficult to estimate what this would be to any concern depending on the day's market for supply of oil. In comparison with such qualities of gas as could otherwise be produced only by the use of cannel, there would certainly be a marked economy. The cost of oil to the Belfast Gas Works for the year ending 30th June 1895 was 2·214*d.* per gallon; and at this rate a saving was effected in cost of production of 1½*d.* per 1,000 cubic feet over the whole make, both of water-gas and of coal gas, the average production of water-gas being one-third that of coal gas. The current year it is trusted will show still better results; but as these would be obtained with oil purchased under peculiarly favourable circumstances, the figures even if available would be misleading. The writer however has not found any reason to change the opinion expressed in his paper read to the Incorporated Gas Institute in June 1894, that with oil at 2½*d.* per gallon carburetted water-gas of 21 candle-power can be produced for less money than 17 candle-power coal and cannel gas.

Extension of Water-Gas system.—Carburetted water-gas had been in use in London for some years prior to its introduction into Belfast; but it seemed to be regarded there rather as a means of meeting an emergency than as a regular factor in the daily make; and the stated cost of the water-gas was so high as to offer but little inducement towards the adoption of the plan. Since the experience in Belfast with the most modern apparatus has been made known, water-gas has been taken up seriously in no fewer than fifteen other cities and towns in the United Kingdom, notwithstanding the sudden rise in price of oil; doubtless but for the latter the number would have been considerably increased. In every place where the apparatus has been got into work it seems to have given entire satisfaction.

In Belfast, after eighteen months' working, it was decided to supersede gradually one of the old retort-houses with water-gas apparatus. At present one bench of retorts has been removed, which was capable of producing 900,000 cubic feet per day; and part only of the space thus acquired has been occupied by four sets of water-gas apparatus, capable of turning out four million cubic feet per day, or 4½ times as much as was produced by the retorts.

Growth of Gas Production.—Meanwhile the demand is still going on apace. Fifteen years ago these gas works were pronounced commercially dead, while yet the consumers have continued to demand from them all the work and service expected only from a flourishing vitality; and a power of growth has been developed, not usually manifested by a moribund concern. Measuring this growth in millions of cubic feet per annum, the progress in decennial periods has been as follows:—

Year ending June . .	1825	1835	1845	1855	1865	1875	1885	1895
Millions of cubic feet .	10*	24	51	109	248	418	718	1169

* Estimated.

This growth is still continuing; and notwithstanding prophetic warnings that the gas industry is already on the wane, the writer ventures to maintain that it has not yet nearly reached its zenith, and to predict that for many a long year the citizens of Belfast will continue to regard with appreciative interest the familiar row of chimneys along the Ormeau Road which pertain to the Corporation Gas Works.

The President proposed a hearty vote of thanks to Mr. Stelfox for his interesting Paper, dealing with a subject of so much practical importance to all concerned with gas works.

EXCURSIONS.*

On TUESDAY AFTERNOON, 28th July, after luncheon in the Exhibition Hall of the Botanic Gardens Park, visits were made to the following Works, in cars provided by the kindness of the Reception Committee. Descriptions of most of these are given in pages 431-457.

Messrs. David Allen and Sons, Printing and Publishing Works, 18 to 24 Corporation Street.

Annadale Brick Works, Ormeau Road.

Public Baths: Falls Road; Ormeau Avenue; Templemore Avenue.

Belfast Ropework, Connswater.

Messrs. Cantrell and Cochrane, Aerated and Mineral Water Works, Cromac Building, Victoria Square.

Messrs. Victor Coates and Co., Lagan Foundry and Engine Works, Ravenhill Road.

Fire Brigade Station, Chichester Street.

Gas Works, Ormeau Road.

Messrs. Harland and Wolff, Shipbuilding, Engine and Boiler Works, Queen's Island.

Messrs. Inglis and Co., Machine Bakery, Eliza Street.

Messrs. McCaw, Stevenson, and Orr, Colour Printing and Publishing Works, Castlereagh Road.

Messrs. W. A. Ross and Sons, Mineral Water Works, 17 and 19 William Street South.

Messrs. Marcus Ward and Co., Royal Ulster Printing, Publishing, and Stationery Works, Dublin Road.

Messrs. Workman, Clark and Co., Engine and Boiler Works, South Yard, Queen's Road; Abercorn Engine Works; and New Yard.

At 5.30 p.m. a special turn-out of the Fire Brigade was witnessed, under the direction of Mr. G. W. Parker, Superintendent.

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* The notices here given of the various Works &c. visited in connection with the Meeting were kindly supplied for the information of the Members by the respective proprietors or authorities.

On Wednesday Afternoon, 29th July, after luncheon in the Exhibition Hall of the Botanic Gardens Park, visits were made to the following Works, in cars provided by the kindness of the Reception Committee. Descriptions of most of these are given in pages 430–459.

Broadway Damask Works, Broadway.

Brookfield Linen Co., Crumlin Road Spinning Mill; and Cambrai Street Weaving Factory.

Messrs. Victor Coates and Co., Princes Dock Boiler Works.

Messrs. Combe, Barbour, and Combe, Falls Foundry, 5 to 15 North Howard Street.

Messrs. Dunville and Co., Royal Irish Distilleries, Distillery Street, Grosvenor Street, Falls Road.

Electric Light Station, Marquis Street.

Messrs. William Ewart and Son, Flax and Hemp Spinning Works, Crumlin Road Mills; and 9 Bedford Street.

Messrs. Gunning and Campbells, Fine-Yarn Spinning Works, 4 North Howard Street.

Messrs. Harland and Wolff, Shipbuilding, Engine and Boiler Works, Queen's Island.

Mr. George Horner, Clonard Foundry, 138 Falls Road.

Main Drainage Outfall Works, Duncrue Street; and Reservoir and Pumping Station.

Smithfield Flax Spinning and Weaving Works, 43 Smithfield.

Ulster Spinning Co., Falls Mills, North Howard Street, Falls Road.

Messrs. Marcus Ward and Co., Royal Ulster Printing, Publishing, and Stationery Works, Dublin Road.

Messrs. Workman, Clark and Co., Shipbuilding Works, North Yard, Spencer Basin.

York Street Flax Spinning Works, York Street.

In the evening the Institution Dinner was held in the Grand Central Hotel, and was largely attended by the Members. The President occupied the chair; and the following Guests accepted the invitations sent to them, though those marked with an asterisk * were unavoidably prevented at the last from being present.

The Right Honourable the Lord Mayor, Alderman W. J. Pirrie, J.P.; Sir James H. Haslett, M.P., J.P.*; Sir William M'Cammond, J.P., ex-Lord Mayor; and Rev. Thomas Hamilton, D.D., President of Queen's College.

Reception Committee.—Mr. Walter H. Wilson, *Chairman*; Mr. Bowman Malcolm and Mr. A. Basil Wilson, *Honorary Secretaries.* Mr. Thomas Andrews, Chairman of the Belfast and County Down Railway; Mr. Robert Ardill; Mr. James Barbour, J.P.; Mr. John D. Barbour, D.L., High Sheriff of County Antrim; Mr. Henry Barcroft, D.L.; Mr. R. B. Belfrage, Great Northern Railway; Sir Samuel Black, Town Clerk; Mr. Josiah C. Bretland, City Surveyor; Mr. Francis F. Byrne; Mr. Walter Chambers; Mr. Victor H. Coates; Mr. Abram Combe; Mr. George Combe*; Mr. Edward J. Cotton,* General Manager, Belfast and Northern Counties Railway; Mr. George P. Culverwell, Engineer, Belfast and County Down Railway; Mr. W. A. Currie,* Secretary to the Belfast Harbour Commissioners; Mr. Samuel C. Davidson; Mr. Wakefield H. Dixon, J.P.; Mr. George Elliott; Mr. John Erskine, J.P.; Sir William Q. Ewart, Bart., J.P.; Mr. G. Herbert Ewart*; Mr. W. D. Ferguson; Professor Maurice F. FitzGerald*; Mr. George F. L. Giles, Engineer to the Belfast Harbour Commissioners; Mr. William R. Gill,* Secretary, Belfast and Northern Counties Railway; Mr. John H. Greenhill; Mr. William Hardy; Mr. Arthur T. Herdman*; Mr. Fritz L. Heyn; Mr. John Horner; Mr. Henry I. Johns, J.P., City Treasurer; Mr. Wm. Redfern Kelly,* Chief Assistant Engineer, Belfast Harbour Commissioners; Mr. Joseph Lewis; Mr. R. Graham Lindsay; Mr. R. P. T. Logan; Mr. James M'Connell*; Mr. Victor A. H. McCowen, Engineer, Central Electric Lighting Station; Mr. F. W. M'Cullough, Resident Engineer, Belfast Water Commissioners; Mr. John H. MacIlwaine*; Mr. Alexander MacLaine, J.P.; Mr. Adam McMeekin; Mr. Robert Meyer, Chief Clerk; Mr. Thomas L. Moore; Mr. James Munce, Assistant City Surveyor; Mr. James Musgrave, D.L., Chairman of the Belfast Harbour Commissioners; Mr. J. W. Philp, Goods Manager, Great Northern Railway; Mr. James Pinion,* General Manager, Belfast and County Down Railway; Mr. John B. Pirrie; Mr. W. J. Pratten; Captain W. B. Ritchie, J.P.; Mr. J. J. Shillington, J.P.; Mr. James Stelfox, Engineer and Manager, Corporation Gas Works; Mr. Frederick P. Wallau; Mr. Francis D. Ward, J.P.; and Mr. Frank Workman.*

Mr. R. C. F. Annett,* Honorary Secretary of the Liverpool Engineering Society; Mr. S. B. Cottrell, President-Elect of the Liverpool Engineering Society; Mr. C. H. Darbishire, J.P.; Mr. Patrick Delany, Postmaster; Mr. George Farren, J.P., Vice-President of the Liverpool Engineering Society; Alderman James Henderson, J.P.; Mr. John W. Hole, R.N., Staff Engineer, H.M.S. "Hannibal"; Mr. Hector MacColl*; Mr. Thomas Macknight; Mr. Arthur J. Maginnis, President of the Liverpool Engineering Society; Mr. John Neilson; Mr. G. W. Parker, Superintendent of the Fire Brigade; Mr. Henry Plews, General Manager, Great Northern Railway; Mr. Edward T. Seddall, Assistant Commissioner of the Royal Irish Constabulary; Mr. Thomas F. Singleton, J.P.,* Commissioner of the Royal Irish Constabulary; Mr. Carl Van der Smissen, Superintendent Engineer of the Hamburg-American line; Mr. P. Smith, Superintendent Engineer of the Peninsular and Oriental Steam Navigation Co.; and Mr. Henry H. West, Past-President of the Liverpool Engineering Society.

The President was supported by the following Officers of the Institution:—*Past-Presidents*, Sir Edward H. Carbutt, Bart., Mr. Charles Cochrane, and Mr. Jeremiah Head; *Vice-Presidents*, Mr. William H. Maw, Mr. Edward P. Martin, and Mr. J. Hartley Wicksteed; *Members of Council*, Mr. John A. F. Aspinall, Mr. Henry Davey, Mr. Bryan Donkin, Mr. Thomas Mudd, Mr. James Platt,* Mr. T. Hurry Riches, and Mr. A. Tannett Walker.

After the usual loyal toasts, the President, in proposing the toast of "The Lord Lieutenant and prosperity to Ireland," regretted that His Excellency was not able to honour them with his presence, being detained in England at this time. In the efforts which he was sure the Lord Lieutenant was making to further the welfare of the whole of Ireland, it was certain he would be cordially supported throughout the rest of the United Kingdom. Although this was his own first visit to the Emerald Isle, he could already appreciate what he had been told of its beauties; and he was confident that, when these were more fully known by the English people, they would

(The President.)

come here, instead of going to Switzerland and other countries. In this way, their own enjoyment would be contributing at the same time to the prosperity of this beautiful island.

The toast of "The City and Trade of Belfast," the PRESIDENT said, gave him the opportunity of expressing his admiration for the Lord Mayor, and of conveying to him the grateful acknowledgments of the Members of the Institution for the way in which his Lordship, himself a Member of the Institution, had welcomed them to Belfast. During the past ten years the growth of the city, he was informed, had been very rapid indeed, probably more so than of any town in Great Britain with the exception of Cardiff; the population of Belfast was now nearly 300,000. The city enjoyed the advantage of not being dependent upon any one trade alone, but of comprising a great many industries, so that the vicissitudes of one or two did not affect too largely the prosperity of the whole. In the shipbuilding trade he believed the establishment of Messrs. Harland and Wolff was not surpassed in extent by even the most enterprising of those on the Clyde. From the extensive flax and linen mills enormous quantities of linen were sent to all the large manufacturing towns in England, apart from what went to the colonies and foreign countries. The tobacco manufacture, the distilleries of Irish whisky, and the manufacture of aërated waters were all conducted on a large scale. Lithography occupied a prominent position; nowhere else were illustrated posters produced of larger size. The rope manufacture gave employment to the wives and daughters of the workmen engaged in the shipbuilding and other works. These and other industries all conduced to the prosperity of Belfast; and he was sure that this, the toast of the evening, would be drunk with enthusiasm, in association with the name of the Right Honourable the Lord Mayor.

The LORD MAYOR in responding said the position occupied by the city of Belfast, and the maintenance and development of the trade and commerce of the port, were naturally matters of the greatest interest and importance to himself and to the rest of the corporation and to the citizens at large. The expression therefore of the good wishes of those joining in the toast was highly gratifying to him, and would be appreciated by all who had an interest in the continued prosperity of the city. The rapid rise and extension of the city, which had been alluded to by the President, had well earned for it the title of "the commercial capital of Ireland." From a small insignificant town of only about 20,000 inhabitants at the beginning of this century, Belfast had increased with such rapidity, and its trade had assumed such large proportions, that it now came next to Liverpool in the amount of its contribution to the inland revenue of the country; in this respect therefore it ranked as the third city in the kingdom. As an industrial centre, its history and its present position he thought were in many respects unique. It had risen more rapidly he believed than any other town or city in the United Kingdom; and for many years past it had enjoyed almost unbroken prosperity. So rapid had been its growth that the extended boundaries defined in 1853 had long been overrun, and with the further extension arranged this year the city would now cover more than 16,000 acres, or nearly three times its area hitherto. From about 20,000 at the beginning of this century, the population had risen in 1831 to 48,000; in 1861 to 120,000; in 1891 to 256,000. Thus thrice in periods of thirty years had it more than doubled itself; while at the present time it was almost 300,000, and would be still greater when the extended boundaries came into force. Of the important industries which had been developed in Belfast and which had been the chief factors in the unprecedented municipal and commercial success of the city, the oldest and undoubtedly the chief was the linen trade. Originally the only important trade of the locality, it now gave employment to some 80,000 persons, of whom probably rather more than 60,000 were women. Next to the linen trade came the industry with which he had himself been all his life connected, namely shipbuilding and engineering. Though only established here in 1859, so successfully had it been carried on that the two shipbuilding yards and their engineering shops, together with the general engineering establishments and foundries—such as those of Messrs. Victor Coates and Co., and of Messrs. Combe, Barbour, and Combe—now employed altogether some 20,000 men. These important industries—the linen trade and shipbuilding and engineering—constituted the mainstay of the trade of Belfast; and fortunately for the stability of the city, as these had grown in importance, other industries also had gradually been started. Some of them might naturally be considered adjuncts of the principal trades, and were in some instances started by those engaged in one or other of these trades. Others however were of an entirely different character, and had been started to meet the increasing demands of the growing population. These included extensive rope-works, large mineral-water manufactories, distilleries, and tobacco factories; of the last, Messrs. Gallaher and Co.'s tobacco factory he believed was now the largest in the world. Among many other important establishments were those for printing, bookbinding, wholesale stationery, and lithography, several of them carrying on an extensive business and employing a large number of persons. Shipping too was a highly important feature in connection with the trade of the port. In addition to the splendid steamers employed in the regular cross-channel service between Belfast and various Scottish, English, Welsh, and continental ports, there were many vessels registered in Belfast trading to all parts of the world. The finest timber and other products of the West, as well as the merchandise of the East, were imported into the commercial metropolis of Ireland; and its export trade was equally world-wide. Its linen goods were sent to the most distant parts of the empire; special kinds of machinery here made were finding markets in the colonies and in foreign countries; and steamers here constructed were carrying British commerce over every sea, while many of them were engaged in the most important passenger lines in the Atlantic, the Pacific, and the East. These facts would afford some indication of the growth and present position of the city and trade of Belfast. Of its rise and progress all its citizens were rightly proud; and he believed the achievements of the past, the continuous development of their trade in all directions, and its present almost unexampled activity, justified a hopeful view with regard to the future. If the present position of his own firm—Messrs. Harland and Wolff—

might be taken as an index of the state of things generally in Belfast, the prospect was certainly hopeful indeed. Already this year they had launched vessels aggregating nearly 40,000 tons, and had been expecting within the year to surpass all previous performances by launching something like 90,000 tons. How far this expectation would be affected by the unfortunate reverse they had just suffered from the disastrous fire of Sunday night, he could not yet say. He highly appreciated the friendly sympathy which had been so readily expressed both to himself personally and also to his firm, in connection with this disaster; and he only hoped that in spite of such a drawback they might even yet see their way to launching that amount of tonnage, which would probably form about one-tenth of the total tonnage that would be launched during the year in the United Kingdom. According to Lloyd's returns there were seven ships of over 8,000 tons under construction in the United Kingdom at the end of last month; and no less than six of these were being built by Messrs. Harland and Wolff, one of the six being over 11,000 tons. This he thought might be taken as an illustration of the present state of trade generally in Belfast. Without going into further statistics, he considered the history of the past and their present attainments were the most convincing arguments as to the soundness of their commercial methods; and that the enterprise and activity which would be observed on all sides in the city were an earnest of future success, and furnished the best reasons for the belief so firmly entertained, at least by himself, that greater developments would yet be witnessed, and that the magnitude of their trade, the extent of their commerce, and the prosperity of all their industries, would astonish even the most sanguine. The foresight and enlightened policy which had characterised in the past the actions of the public bodies of the city constituted, as all would agree, a most important element of its welfare; and those bodies he was confident would prove themselves equally alive in the future to the necessity of moving with the times, and anticipating the requirements of the various trading interests in the community. As Lord Mayor of Belfast he was glad to regard the fact of the summer meeting of the Institution of Mechanical Engineers being held

(The Lord Mayor.)

here as a gratifying acknowledgment of the growing fame and importance of the city and trade of Belfast.

Mr. J. HARTLEY WICKSTEED, Vice-President, in proposing the toast of "The Queen's College," said the Members of the Institution appreciated highly the position and the beauty of the College, and the admirable accommodation it had afforded them for the present Meeting. That stately edifice, with the noble façade of its great western front, its varying lines of mullioned and traceried windows, its projecting oriels and subdued buttresses, and its fine gothic entrance surmounted by the lofty central tower with battlements and pinnacles, had rightly been pronounced by Macaulay to be worthy to stand in the High Street of Oxford; and the Examination Hall, in which their Meeting had been held, was one of the noblest college halls to be found anywhere. In the grounds surrounding the College he was pleased to see that there was now being erected for the Students' Union a new building, the cost of which he understood was defrayed by voluntary contributions, and not by State funds. This welcome illustration of the public spirit and liberality of the citizens of Belfast he hoped would be the beginning of yet further progress, in such a direction, for instance, as the building of a residential hall wherein the students might congregate and reside, whereby that collegiate spirit might be engendered, for which the colleges in Oxford and Cambridge and other universities were so celebrated. It had been one of the great pleasures of this visit to make the acquaintance of the President of the College, Rev. Dr. Hamilton, and of the Professor of Engineering, Professor Maurice F. FitzGerald. Glancing at random at the history of the College from its opening in 1849, he found it had produced such men as Sir William MacCormac, and Sir Robert Hart, Bart., of Peking, Inspector General of the Imperial Maritime Customs of China, and some of those most eminent in the professions, in the arts, in literature, in the church, at the bar, in the diplomatic service, and in the army. The College had also trained distinguished men who held leading positions in industrial life. In order to carry out more effectually in the future this last branch of its work, some change would be necessary; and he hoped that the Queen's College, which in England was looked upon as the University of Belfast, would develop somewhat with the times on its mechanical engineering side. In the late Dr. James Thomson, the brother of Lord Kelvin, the College had possessed a teacher who had achieved distinction as a professor of engineering both here and afterwards in Glasgow University, and had also himself been a distinguished inventor.

Rev. THOMAS HAMILTON, D.D., President of Queen's College, said it had been a sincere pleasure to himself and to all the authorities of the College to be able to offer hospitality to so distinguished a body as the Institution of Mechanical Engineers, whose first two Presidents had been George and Robert Stephenson, and among whose present Members were such prominent citizens of Belfast as the Lord Mayor, and Mr. Walter H. Wilson, and others whose names were found on the list of the Reception Committee. The visit of the Institution however had in his own mind been associated with two regrets. The first was that the Queen's College was not a university, and that it was therefore destitute of the power of conferring any kind of academic distinction on the President and other Members of the Institution. Had they that power, as it was possible that some day they might have, he knew of no duty which would have been more welcome than that of conferring such a degree as that of Doctor of Science upon them. The other regret was that Queen's College had at present no chair of Mechanical Engineering. One reason no doubt was that, when the College was founded fifty years ago, in no college in the United Kingdom was there such a chair; and since that date, the experience of Queen's College had at various times confirmed the truth of the saying that the heart of the British Treasury was hard. If such a chair were ever to be established, the means he thought must be looked for, not from the State, but from the source already alluded to by the proposer of the toast, namely the wealth and public spirit of the citizens of Belfast. The late Sir Edward Harland, Bart., who took the deepest interest in the College, had often expressed his regret that they had not there the

(Rev. Dr. Hamilton.)

means of teaching in a more adequate manner the important subject of mechanical engineering. So deeply too had this great want been felt by the present professor of engineering, Professor FitzGerald, that at one time he had even proposed to be at the cost himself of providing such apparatus as would enable him in some degree to supply the place of such a chair. When next therefore the Institution visited Belfast, which he trusted would be soon, he hoped the two wants he had drawn attention to would be supplied: that the College as a university would be able to perform such graceful duties as he had alluded to; and that they should have at their disposal the means of teaching in an adequate manner the great subject, for the promotion of which the Institution of Mechanical Engineers existed. But while not possessing these advantages, Queen's College had nevertheless been able to make her mark in the direction of mechanical engineering. A notable instance was that referred to by Mr. Wicksteed, of the late Professor James Thomson, whose fame, he imagined, had perhaps been unduly overshadowed by the greater reputation of his distinguished brother, Lord Kelvin. But a number of his inventions and works, embodying the results of long experimental research, were of the utmost value, and rendered him worthy, in the opinion of eminent authorities, to stand side by side with that illustrious peer. Queen's College had trained the lately appointed professor of mechanics in the Royal College of Science, London—Professor John Perry; and all over the world her alumni were to be found, occupying prominent positions on railways and in other great engineering enterprises. The College, he was happy to say, was in a state of vigorous health. Fifty years ago she had only ninety matriculated students; last session there were four hundred. Half a century ago she was a poor college, and had yet to make her way in the world; since then she had given to Ireland and to the world men like Sir Robert Hart, Bart., G.C.M.G., Sir David Millar Barbour, K.C.S.I., late Finance Minister of India, and Sir William MacCormac, M.D.; while to the church, to medicine, to the bar, and to the manifold departments of commercial life, she had furnished hundreds of able men, who in their various professions and businesses maintained the honour of their Alma Mater, and were rendering noble service to their country. It had been his fortune to be at the head of the College for only seven years; but during that comparatively short period he had seen sufficient to convince him of the great possibilities that lay here. As the years rolled by he hoped and believed it would be found to be fulfilling more and more the great purposes contemplated in its establishment by the State; and to be more and more deserving of the eulogium passed upon it a few years ago by a distinguished Irishman, not an Ulsterman, when he described Queen's College, Belfast, as the greatest glory and pride of the northern province.

Mr. Thomas Mudd, Member of Council, in proposing the toast of "The Belfast Harbour Commissioners," said that, as a comparative stranger to the city of Belfast, he could not speak much from his own knowledge regarding the details of the works carried out by the Harbour Board; but it was apparent to any one paying a visit to the harbour and docks that a vast amount of energy and skill had been expended in carrying out these extensive works, and that the commerce of the port of Belfast owed much to the fostering care displayed in the enlightened and advanced policy pursued by the Harbour Commissioners. Not only had enormous works been completed in the way of providing dock and quay accommodation, but one of the largest and most important undertakings carried out by the Board, and one fraught with the greatest possible benefit to navigation, had been the straightening of the channel, which he understood had been initiated, like so many other works in Belfast, by the late Sir Edward Harland, Bart. Apart from the conspicuous ability with which the Harbour Board had improved the port of Belfast, there was also another reason why the toast should be heartily received, namely because they had done so much to help in making the visit of the Institution a pleasant and a successful one, by arranging steamers for enabling the Members conveniently to inspect the harbour, and by their kind hospitality in other ways.

Mr. James Musgrave, D.L., Chairman of the Harbour Trust, said that, while the present Commissioners, like their predecessors in

(Mr. James Musgrave, D.L.)

the Trust, had been able with the help of the engineering profession to overcome obstacles which without that aid would have been insurmountable, they looked forwards with confidence to being provided from time to time by the Members of this Institution with such improvements in mechanical appliances as should enable them to maintain and extend the accommodation of their harbour, and to keep pace with its increasing trade. Tomorrow they would have the pleasure of showing the Members through the upper reaches of the harbour, which he had no doubt would present many points of interest, because, unlike some famous harbours which were almost perfect as formed by nature, this might be styled a self-made harbour. Within the period of modern history Belfast had been little more than a village, incapable of approach by sea except by small craft. Close to the Queen's Bridge, where great steamers were now berthed, there had been a shallow ford across the river Lagan, and the seaport of the district had been at Carrickfergus. Since those days, by gradual and judicious engineering works, extending over many years, and paid for by money in great part borrowed from those who had been enriched by the commerce the harbour had created, the condition had at length been arrived at that vessels drawing sixteen feet of water could approach or leave the quays at any hour; and at high tide transatlantic steamers up to twenty-five feet draught could steam directly into a dock, where they could lie in water twenty-six feet deep at low tide without the necessity of dock gates. Such was a brief outline of the physical results accomplished by engineering skill, assisted by powerful mechanical appliances. The social results had been equally striking. Side by side with the harbour, there had grown up a great commercial city, in which every Belfastman took an honest pride. Owing to an important meeting of the Harbour Commissioners taking place yesterday, they regretted that they had been prevented from accompanying the Lord Mayor, who was himself a member of their Board, in receiving and welcoming the Institution at the opening of the proceedings yesterday morning.

Mr. John A. F. Aspinall, Member of Council, in proposing the toast of "The Irish Railways," alluded to the hospitality which had been extended to the Institution by the leading lines, particularly by the three running from Belfast, by whom the Members had been invited to avail themselves of the special free trains for the Excursions in connection with the present Meeting. Having been formerly connected for about ten years with the Great Southern and Western Railway, he felt special gratification in proposing the toast of prosperity to the Irish railways, which did such good work, and whose directors were making such strenuous efforts for attracting the tourist traffic to the charming scenery in the different parts of the country through which their lines ran. Naturally the Institution could not help feeling a great interest in the so-called light railways, which, originally planned by the government, had been materially strengthened and improved by the money spent upon them by the main railways themselves, and which were intended not only for the purpose of opening up many of the beautiful districts hitherto almost inaccessible, but also for enabling the fishing industry of the Irish coast towns to be brought into communication with the great markets of England. Whether these light railways were connected with the northern lines of Ireland, or ran from Galway to Clifden, or from Killorglin to Cahirciveen, the Institution would heartily wish that the enterprise of the main railways which were working them should meet with the success it deserved. Whenever coming to Ireland he always felt that the main lines had here an advantage over the English railways in respect of their gauge. There was no doubt that the extra 6½ inches width of the Irish 5 ft. 3 ins. gauge was valuable to locomotive engineers, who found that the width available with the 4 ft. 8½ ins. gauge was far too narrow for the convenient accommodation of all the machinery required in the present locomotives.

Mr. Thomas Andrews, Chairman of the Belfast and County Down Railway, believed the explanation of the cordial reception of this toast was that it had been proposed by an Englishman; no Irishman could have dared to venture on so dangerous a subject.

(Mr. Thomas Andrews.)

For most of those present must have heard that an Irishman had occasionally a grievance; and whenever the long list of Irish grievances was recited, it always began with the railways; and it always ended as it began. Some of the trains were slow, and stopped at every station: a most intolerable grievance, which a true Irishman would stand no longer. Other trains were fast; but then they had the audacity to pass the complainant's station without stopping, and thereby led him to indulge in threats against the directors if they did not mend their management. What was the use of a body of mechanical engineers, if they could not make fast trains stop at every station for the convenience of his countrymen? Without regarding Irish railways as models of good management, or British railways either, he believed they were quite as well managed as any other large business in this country. Taken as a whole, they were giving a moderate return to their shareholders; and he considered those who occasionally tried to persuade the inhabitants of this distressful island that they might look for a mitigation of their many and serious difficulties in a general reduction of railway rates were simply raising hopes which were doomed to disappointment, in the near future at any rate. That here and there exorbitant rates did exist, which required revision, he did not deny. There were only three sources that he knew of, from which a reduction of rates could come: either from a reduction of working expenses through better management, or from an increase of receipts through larger traffic, or from a reduction of dividends. Believing that the railways were not badly managed, he considered the working expenses were more likely to increase than to diminish. Greater receipts through larger traffic would not be drawn from a diminishing population of four and a half millions, until great changes took place. And a reduction of rates to the extent of only one-sixth would wipe away almost, if not altogether, the dividend upon the ordinary shares, and would render this property practically valueless. A reduction of rates he admitted was possible through purchase of the railways by the State; but other difficulties then arose, which he should not enter upon tonight. On the Belfast and County Down Railway he maintained that all the goods were carried out of and into that county which were to be had; the excursion fares were low enough to please the most exacting, and no reasonable reduction would induce business men to travel more frequently than they did already. No one however would welcome the day when a reduction of rates should become possible more than he should. Of late years the County Down Railway had not been unsuccessful. Last February had witnessed the jubilee of its opening. For the first twenty-seven years of its history the dividend on the ordinary shares had averaged less than one per cent.; for the last eleven half-years it had continuously been six and a half per cent. Where then was the relief to come from, which was so sorely needed for the agriculture and the industries of this land? The answer he hoped would be found in the unanimous and most able report of the Recess Committee, whose members had the confidence of their countrymen, and had been holding a lengthened session in Dublin, in touch with a consultative committee in Belfast. They had sent the best men they could obtain to make exhaustive investigations on the continent; and their report would show how successive governments had hitherto failed in their duty to the agriculture and industries of the United Kingdom, and that, unless we now took a lesson from foreign countries, and fostered our agricultural and manufacturing resources by the same methods which had been so successfully practised on the continent for many years, we should be utterly distanced in the race. So far as railway enterprise was concerned, he need scarcely say how much it owed everywhere to the labours of mechanical engineers.

The toast of "The Reception Committee and the Honorary Secretaries," proposed by Mr. WILLIAM H. MAW, Vice-President, was acknowledged by Mr. WALTER H. WILSON, Chairman of the Committee, and Mr. BOWMAN MALCOLM and Mr. A. BASIL WILSON, Honorary Secretaries.

Mr. JOHN D. BARBOUR, D.L., High Sheriff of County Antrim, in proposing the toast of "The Institution of Mechanical Engineers," recalled the incalculable benefits conferred upon humanity by the profession of which the Institution was the representative. The presidential chair had been occupied by many celebrated men, whose names were associated with inventions and researches of the highest value to mankind; and in the art of providing mechanical engineers throughout the world with the iron and steel required for the realisation of their conceptions, probably no one had done more than the present distinguished President of the Institution.

The PRESIDENT in responding was glad to say the Institution was in a flourishing condition, continuing to increase in numbers by the election of new members, whose qualifications for admission were carefully scrutinised by the Council. The new house intended to be built in St. James' Park had been thus far delayed by a recent strike in the building trade, and by other hindrances; and he hoped a start would soon be made, and that a year or two would see the realisation of their wishes. The present Meeting he need scarcely say had been one of the most successful and enjoyable Summer Meetings ever held by the Institution, thanks to the attractive arrangements matured for them by their local friends, and to the warmth of the reception accorded them in Belfast.

Sir EDWARD H. CARBUTT, Bart., Past-President, in proposing "The Press," said he had a pleasant recollection that fifty-two years ago his father had been invited to come to Belfast to contest one of the seats in parliament. It was thirty-five years since he himself had first visited the city, and he had repeatedly done so since; and one of his most valued friendships here had been with the late Sir Edward Harland, Bart., whose loss was so deeply regretted by all who had known him. The Press had done much to elevate and enlighten the country; and its technical branch in particular had rendered valuable assistance to engineers. The Irish press was deserving of compliment upon its enterprise, and upon the variety and wide extent of the views it gave, which were of benefit to all classes, and to the commercial community especially. One of the gentlemen who would respond to the toast had recently written a book entitled "Ulster as it is," which he understood was a valuable contribution to the history of this important province.

Mr. James Henderson, managing proprietor of the Belfast News-Letter, thought the eulogy bestowed upon the Press by the proposer of the toast was well merited; and for their part journalists naturally felt themselves much indebted to mechanical engineers for the great progress made during recent years in the collection and diffusion of information. One important matter was the manufacture of paper, which he was glad to say was now being made close to Belfast, and in such quantities as to supply England and Scotland as well. With the printing press mechanical engineers had had more to do than any one else, from the old hand press, with which he could well remember the great difficulties accompanying so slow and tedious a process, to the modern rotary machine throwing off something like 40,000 copies an hour with the assistance of only three or four attendants. Stereotyping too was another important benefit received from mechanical engineering; but the greatest improvement of all in recent years he thought was the linotype machine, of which he had now a number in use in his establishment, and he should be pleased to show them in operation to any of the members of the Institution who would like to see them at work. This he regarded as one of the most wonderful inventions in the printing trade during the present century.

Mr. Thomas Macknight, editor of the Northern Whig, recalled the saying of Charles James Fox, that every people sooner or later had the government which they deserved; and he believed it was equally true that every people had the Press they deserved. The press of Ulster gave a fair representation of Ulster public opinion, which was all that could be reasonably expected. The President's remark that this was his first visit to Ireland served to illustrate what seemed to him to be one of the greatest difficulties under which the Emerald Isle laboured. People in England and Scotland seemed to think Ireland was so far off, and that it was so difficult to come here; and he was therefore glad now to see one association after another coming over, and to record that all who did so spoke in the highest terms of the province of Ulster and of the people of Belfast. Though not born in Ireland, from a pretty long experience of the

(Mr. Thomas Macknight.)

country he could say of the people that the more they were known the more highly would they be respected, and the more truly would the nobility of their independence and self-reliance be appreciated. In regard to his book on Ulster, to which the proposer of the toast had so kindly alluded, he had had the gratification of hearing from the publishers that seldom had they known any book dealing with controversial subjects which had been better received by the newspapers of all shades of public opinion, whether in England, Scotland, or Ireland. This he regarded, not as a compliment to himself, but as a high compliment to the independence and impartiality of the Press.

On Thursday, 30th July, a visit was made to the Belfast Harbour Works (pages 422–429). Assembling at the Harbour Office, Corporation Square, the Members were conducted over the Harbour Works by Mr. James Musgrave, D.L., Chairman, Mr. W. A. Currie, Secretary and General Superintendent, Mr. George F. L. Giles, Engineer, and Mr. W. Redfern Kelly, Chief Assistant Engineer. The Clarendon Dock with Nos. 1 and 2 graving docks, and the new branch dock, were first visited; and thence, by means of the harbour tug "Lion" and a launch, the new Alexandra Graving Dock, and the Abercorn Basin, alongside the works of Messrs. Harland and Wolff. Returning from the Harbour, the Members were invited to luncheon by the Commissioners in the new banqueting hall of the Harbour Office.

In the afternoon an Excursion was made to Larne by special free steamer "Princess May," by invitation of the Larne and Stranraer Steamship Joint Committee, passing under the Gobbins cliffs. Afternoon tea was provided on board by the kindness of the Reception Committee.

On arrival at Larne Harbour the Alumina Works of the British Aluminium Co. were visited under the guidance of Mr. James Sutherland, Manager (pages 380–389). The return to Belfast was by special free train, by invitation of the Directors of the Belfast and Northern Counties Railway.

In the evening the Members were invited by the Right Honourable the Lord Mayor, Alderman W. J. Pirrie, J.P., and the Lady Mayoress, to a Conversazione in the Free Library and Art Galleries.

On Friday, 31st July, three alternative Excursions were made.

By special free train to Portrush, by invitation of the Directors of the Belfast and Northern Counties Railway. Thence the Members proceeded on cars to visit Dunluce Castle and the Giant's Causeway.

By special free train to Parkmore, viâ Ballymena, by invitation of the Directors of the Belfast and Northern Counties Railway. Thence brakes were taken to visit Glenariff Glen, near Cushendall.

By special free train to Warrenpoint, by invitation of the Directors of the Great Northern Railway. There the Members embarked on the new excursion steamer "Pioneer," fitted with large-blade twin screw-propellers partially submerged, for a cruise in Carlingford Lough, by invitation of Mr. Henry Barcroft, D.L., and friends. After luncheon at Rostrevor, special coaches were taken for a drive round the coast at the foot of the Mourne Mountains to Newcastle. Thence the return to Belfast was by special free train, by invitation of the Directors of the Belfast and County Down Railway.

BELFAST HARBOUR.

The following description was kindly prepared by Mr. George F. L. Giles, Engineer to the Harbour Commissioners, for the guidance of the Members in visiting the Harbour Works on Thursday, 30th July. It is illustrated by the plans shown in Plates 104 and 105.

Starting from the Queen's bridge, which forms the southern limit of the harbour proper, and passing along the Donegall quay on its western side, which with the Princes quay extends for a length of 3,125 feet or 0·59 mile, some idea will be gained of the vast extent of the cross-channel trade to Belfast, as evidenced by the huge piles of merchandise which pack almost to the roof the lofty shed built along the whole length of these two quays. Donegall quay was re-constructed in timber work in or about 1847, and was rebuilt in concrete with granite ashlar face-work by the Harbour Commissioners between 1879 and 1886, from the designs and under the supervision of Mr. T. R. Salmond; the substructure consists of concrete between closely driven sheeting piles, and the superstructure of rubble masonry faced with granite ashlar; the total cost, including sheds, tramways &c., was £124,745, or £39 12*s.* per lineal foot.

Clarendon Dock.—Separating the Donegall and Princes quays is the entrance to the Clarendon dock, which is spanned by a double-road swing-bridge, built in 1882 at a cost of £17,000; the bridge itself cost £4,500, and its foundations £12,500. The dock, which lies at the back or westward of the two quays, has an area of 4 acres. It was built between 1847 and 1850, and is now principally used for small coasting vessels, the depth of water being limited to about 10 feet at low water, which however at the time the dock was constructed was amply sufficient for the class of vessels then using the port. Leading out of the west side of the dock are two small dry docks, one of which was constructed in 1800 and the other in 1826; they are now somewhat out of date, but are still extensively used by small vessels. In the immediate vicinity are situated the harbour workshops and stores, which include fitters', smiths', and carpenters' shops, as well as a slipway for the repair of barges &c. On the Princes quay to the northward of the goods sheds is situated a fixed crane, having a lifting capacity of 25 tons. It was erected in 1883, and is capable of being worked either by steam or manual power at a radius of 36 feet.

Princes Dock, and new Branch Dock.—A little further to the north lies the old Princes dock of $3\frac{3}{4}$ acres, formerly called Dunbar's dock, which was purchased in 1843, and is the oldest dock in existence in Belfast. The entrance to it has lately been closed, in order to allow of an extension of Princes quay; and the dock is now being connected northwards with the Spencer basin through the new Branch dock. The Princes quay is executed in concrete work, like Donegall quay, and is 850 feet long; including sheds &c. it cost £34,762, or about £40 19*s.* per lineal foot. A 25-ton crane was erected on it in 1888, costing £1,692. The Branch dock was commenced in 1889, and was intended mainly for the transatlantic trade. It is constructed of rubble masonry faced with granite ashlar; the excavations and dock walls alone cost £68,898. It has a depth of water of 26 feet at low water, which is sufficient to allow any vessel likely to visit this port for some years hence to lie afloat at dead low water; and when completed with its extension at present in process of construction the water area of the dock will be about 10 acres altogether. On either side of the new Branch dock are large and commodious goods sheds, which are at the present moment being supplemented by others of similar design.

Spencer Basin.—The Branch dock communicates with the Spencer basin, which has a depth of water of about 15 feet at low water, and is principally used by vessels in the timber trade. The basin is 7 acres in extent, and was built between 1864 and 1871 by Mr. Lizars, the then engineer to the Belfast Harbour Commissioners. Both this and the Dufferin dock opening out of it are of rubble work faced with random rubble, and together cost about £155,000.

Dufferin Dock.—The Dufferin dock of 3¼ acres area is a floating basin with 25 feet depth of water, which is used largely by the timber and grain trades. It was opened in 1871.

Milewater Basin.—Following the course of the river northwards, and extending for a length of 2,090 feet beyond the Donegall and Princes quays, of which it is in fact an extension, runs the Albert quay, built of timber between 1872 and 1875 at a cost of £49,500, or about £24 14*s*. per lineal foot. It is principally used for coal and iron ore, and large quantities of coal are stored along the back of the quay. Beyond the entrance to the Spencer basin at the north end of the Albert quay is situated the Milewater basin of about 3 acres area, which was formed about 1871 and provided with timber quays in 1885 and 1893. It is principally used as a fitting-out basin for the vessels built in the ship-yard of Messrs. Workman, Clark and Co., part of which adjoins the basin on the north side.

Victoria Channel.—Beyond Messrs. Workman, Clark and Co.'s ship-yard the harbour proper terminates northwards in what is known as the second cut of the Victoria channel, a length of about half a mile between the west and east Twin Islands, which was completed about 1849 and diverted the river bed from a tortuous channel into one going perfectly straight to the commencement of Belfast Lough. The river channel was again diverted from this point by means of the Victoria channel extension, which was one of the most important improvements in connection with the harbour. The length of this channel, which was dredged through the intervening sandbanks and slob-lands with a width of 300 feet between the bottoms of the slopes, is about four miles, and entailed the removal of about 3,762,500 tons of soil. The work was commenced in 1885, and brought to a conclusion in 1891 at a cost of about £70,000. The new channel has a depth of over 17 feet at low water, and this depth of water has since been carried right up to the heart of the city. There were two hopper dredgers in constant use, costing about £21,000 each.

On returning from the Lough, and traversing the east side of the harbour, the first point of interest to be noticed is a large new slip, which has been reclaimed from the slob-lands and leased to Messrs. Workman, Clark and Co., but still awaits development.

Alexandra Graving Dock.—Next comes the Alexandra graving dock, which until quite recently was reckoned the largest dry dock in existence; it is 830 feet long, 92 feet wide at coping level, and 50 feet wide on the floor, with a depth of water over the sill of 25 feet at ordinary high-water level. It was opened by the late Prince Albert Victor of Wales in 1889. The work is executed in concrete, faced with concrete of finer quality; the entrances and coping are of granite. The cost of the dock alone was £93,448; and including the Alexandra and Victoria wharves &c. the total cost was about £150,000. The engines, pumps, and machinery for pumping the water from the dock were so designed that 10,000,000 gallons of water, the contents of the dock, can be discharged into the entrance basin within two hours and a half. The engines are two pairs of horizontal compound non-condensing of 500 H.P. combined, having their cylinders placed at right angles, each pair acting direct on one crank-shaft with sweep cranks, for working with a steam-pressure of 80 lbs. per square inch. The high-pressure cylinders are 20 inches and the low-pressure 31 inches diameter, the stroke in both being 24 inches. At the bottom of the two pump wells are fixed two cast-iron centrifugal pumps, with runners 7 feet diameter secured to the vertical pump-shaft. The engines are so designed that either or both pumps may be worked at the same time. The dock is supplied with every convenience for the economical and rapid repair of vessels lying in it, and can be divided transversely by ship-shaped caissons into three different lengths of 300 feet, 200 feet, and 300 feet. The caissons cost about £4,830 each, for entrances 80 feet wide, the coping being 31 feet above the dock sill. There are several wharves and jetties in connection with the dock; and on the Alexandra wharf is a 100-ton derrick crane, alongside which the quay has a depth of 24 feet at ordinary low-water level.

100–*Ton Derrick Crane, Alexandra Wharf.*—This crane is capable of lifting loads of 100 tons at a radius of 50 feet; 80 tons at a radius of 60 feet; and 60 tons at a radius of 70 feet. It is used for the shipment of heavy machinery and boilers, and for masting; and is one of the finest and largest derrick cranes in the United Kingdom. Steel predominates throughout the structure, including the gearing, which is chiefly enclosed between the cheeks of the mast. The latter works in a massive centre step, resting on concrete, in which is fixed a steel pivot 15 inches diameter, bearing upon discs of steel and phosphor-bronze. The pivot is held in its place by a bottom girder, which is fixed at the base of the mast, and also receives the steps of the jib. At the top the mast has a strong T shaped 15-inch pin of mild steel, cottered down to a casting fixed to the framing; and to this pin are secured the slewing straps, containing the pulleys for the wire ropes which regulate the range of the jib. The combined stress due to the jib suspension and to the load is borne by this pin, and is opposed by the resistance of the back stays. The latter are single, and are made on the box principle; as also is the diagonal stay between the lower portion of the back legs. The feet of the back stays are held down by steel bolts with steel cotters; they are in two lengths, with intermediate castings to allow of expansion and contraction. The jib is double, and has two steel cap-pulleys for loads up to 26 tons, and four pulleys for the main load up to 100 tons. It is raised and lowered by an engine with double 12-inch cylinders of 16 inches stroke and with link reversing-motion, working direct through a worm on a worm wheel 8 feet 5⅜ inches diameter by 8½ inches broad and 3¼ inches pitch. The steel pulleys, 5 feet in diameter, are split at the bosses, and are bushed with gunmetal. The main block has three similar pulleys, the hook or sling working on a series of conical friction-rollers for easy turning. The hoisting engine has also double cylinders and link reversing-motion, like the luffing engine. The steel wire-rope is 7 inches in circumference, and has six strands, each proved with a load of over 30 tons. The barrel has three separate ropes; one for light loads, which hangs beyond the main load, and is double; the second for the main load (7 fall), and the third for luffing the jib (8 fall). They are wound separately on three barrels spirally grooved, which are revolved by a pair of cylinders 8 inches diameter with 12 inches stroke. There is a link reversing-motion, with two pinions, one on each side, working into a steel rack. All the engines are easily under the control of one man, and are protected from the weather by means of a glazed enclosure. The boiler is of mild steel, 6½ feet diameter and 14 feet high, and has nine cross tubes. It was tested to 160 lbs. per square inch, and is fed by a donkey engine. The total weight of material used in the construction of the crane is 220 tons. The minimum factor of safety is considerably over 6 to 1, and for the wire-rope over 10 to 1. The bottom of the main lifting block gives a clear hoist of 90 feet; the jib is 100 feet long, and admits of a range, from the centre of the revolving motion to the drop of the main block, of between 30 and 80 feet, with a large amount of swinging movement within the limits of the back stays, rendering the crane capable of lifting from the quay and over the bulwarks of a vessel its heaviest working load, and depositing it in the ship with the greatest nicety. The foundations for the crane cost £7,596, and the crane itself £5,970.

Further southward is the south shipbuilding yard of Messrs. Workman, Clark and Co.; and the Victoria wharf, a timber structure erected in 1894, principally for the convenience of the shipbuilding companies in fitting out new vessels. Alongside the Victoria wharf there is a depth of water of 16 feet at ordinary low tide; and the water space opposite the wharf and between it and the river forms the launching basin for the north slip of Messrs. Harland and Wolff's shipbuilding yard, whence have been launched many famous vessels, amongst others the "Teutonic" and "Majestic," of 10,000 tons; and at the present time there is a vessel on one of the slips of fully 14,000 tons capacity.

Abercorn Basin.—Continuing southward alongside the workshops of Messrs. Harland and Wolff, the south slips of this firm are reached, and then the Abercorn basin, which was built between

1864 and 1867 of rubble work, similar to the Spencer basin and Dufferin dock, at a cost of £24,000. The depth of water is 11 feet at ordinary low-water level, and the average area of the basin is about 11½ acres. Within it are two large and strongly-built wooden jetties of 350 and 317 feet length, which are used entirely by vessels lying alongside whilst being fitted out; No. 1 jetty 350 feet long, built in 1884, cost £6,736; No. 2 jetty 317 feet long, built in 1885, cost £5,435. For the purpose of masting large vessels or placing boilers and heavy machinery on board, a large pair of masting sheers capable of lifting 60 tons was erected in 1870 on the eastern side of the basin at a cost of £2,000. Leading out of the Abercorn basin is the Hamilton graving dock, completed in 1867 at a cost of £40,000; it is 470 feet long and 84½ feet wide at the coping level and 50 feet wide on the floor; the entrance is 60 feet wide at the coping level, with a depth of 15½ feet of water over the sill at average high-tide level. The east quay of the basin is principally used for the fitting out of vessels, while the south quay is exclusively used for coal. Close to the south-east corner of the basin is the electrical generating station, which supplies the power for lighting the Queen's quay, Abercorn basin, and Hamilton graving dock, with 31 arc-lamps of 1,000 candle-power each.

Queen's Quay.—South of the Abercorn basin, and between this and the Queen's bridge, is situated the Queen's quay, which was re-constructed between 1875 and 1877 at a cost of £63,000, or about £29 3*s.* per lineal foot. It has a frontage of 2,150 feet, and a depth of water of about 15 feet at ordinary low-water level. It is used principally for the coal and iron trades, and is provided with a large number of 2-ton locomotive steam-cranes, and one locomotive steam-crane capable of lifting 7 tons with a radius of 30 to 45 feet, constructed in 1895 at a cost of £1,695.

Between the Queen's quay on the east side and the Donegall quay on the west side the river is traversed by two steam ferries, one placed near the Abercorn basin, and the other opposite the terminus of the Belfast and County Down Railway. Three steamboats constantly ply at these ferries, and greatly facilitate passenger traffic between the two sides of the river; the latest was built in 1889 at a cost of £937 to carry 120 passengers, and the working expenses, exclusive of interest or depreciation, are about £7 4*s.* per week. The Queen's bridge forms the southern limit of the water navigable for sea-going vessels.

Locomotive Steam-Cranes.—There are at present thirty-four of these useful appliances, some having a lifting capacity of 2 tons and others of 3 tons. The cost of the latest 3-ton steam-cranes of 45 feet radius, constructed in 1894 and 1895, was about £800 each.

Goods Sheds.—The cost of the double-span goods-sheds, 112½ feet clear in width, is about £18 15*s.* per lineal foot of length. The single-span sheds of 80 feet width cost £15 12*s.*, and of 60 feet width £10 per lineal foot of length.

Tramways.—About 8½ miles of tramways for railway traffic are laid on various parts of the harbour.

Range of Tides in Belfast Harbour.—The level of the sill of Clarendon No. 2 graving dock is the harbour datum. Ordinary high water of spring tides averages 10 ft. 8½ ins. on the sill, and of neap tides 9 ft. 10 ins. Ordinary low water of spring tides averages 1 ft. 3½ ins. on the sill, and of neap tides 2 ft. 2 ins.

The shipping cleared from the port of Belfast during last year 1895 amounted to 2,150,232 tons; and the revenue of the Harbour Trust exclusive of pilotage was £139,190, leaving a net surplus revenue of £10,848 for the year. Eighteen vessels constructed in the shipbuilding yards at this port cleared during 1895, measuring 92,947 tons gross and 60,208 tons net.

BELFAST MAIN DRAINAGE WORKS AND PUMPING STATIONS.

The following particulars were furnished by the kindness of Mr. Josiah C. Bretland, City Surveyor.

Main Drainage Works.—The act of parliament for the construction of these works was obtained in 1887. The works were immediately afterwards commenced, and have now been practically completed at a cost of about £300,000. Previous to their execution the sewers of the city discharged into the River Lagan and its tributaries, causing a pollution almost intolerable. Two large trunk sewers with numerous branches have been constructed, and are known as the high and low-level intercepting sewers: the former drains the higher districts by gravitation, and the latter the lower districts by pumping.

A storage reservoir situated in the slob-lands recently reclaimed from the sea, having a capacity of about five million gallons, receives the sewage until the proper time of discharge during the first portion of the ebb tide. The discharge from the reservoir is conducted along a covered timber sewer, about one mile in length, laid in the tideway as far as that portion of the Lough known as Whitehouse Roads, where a strong ebb current northwards prevails. The foundations of the reservoir and adjacent works are upon a soft alluvial formation, and are formed throughout of piles and concrete.

The sewage from the County Down side of the city is passed under the river Lagan, on the southern side of the Queen's Bridge, by a syphon formed of two cast-iron pipes, each 3 ft. 9 ins. diameter, embedded in concrete.

Pumping Stations.—The machinery at Duncrue Street pumping station, where the sewage is lifted about 11 feet, consists of three multitubular boilers, each 12 feet long by 8 ft. 6 ins. diameter, with a working pressure of 90 lbs. per square inch. They are fitted with Grainger's forced draught, and a Green's economiser of 96 tubes. The chimney is 100 feet high. There are two compound condensing horizontal pumping engines, each capable of discharging 750 cubic feet per minute; and one tandem compound condensing centrifugal pumping engine, with a capacity of 1,500 cubic feet per minute. The pumps of the horizontal engines are worked at right angles, and have a stroke of 3 feet, with plungers 3 feet diameter. In addition to these there are two high-pressure centrifugal pumping engines for dealing with storm water, each capable of discharging 2,500 cubic feet per minute.

The function of the pumping station at the outfall works is to deliver into the reservoir such of the sewage as cannot be dealt with by gravitation, and thus to maintain a constant flow in the main trunk sewer. At this station the machinery consists of three boilers with economisers, same as at Duncrue Street. Two sets of compound centrifugal pumping engines have been provided, each capable of discharging 1,000 cubic feet per minute, and one similar engine 1,500 cubic feet per minute, through the maximum lift up to the top water level in the reservoir. Room has been left in this station for the addition of another boiler and engine when required, as well as for extension of the reservoir itself. There is also a set of hydraulic machinery, working up to a pressure of 750 lbs. per square inch, for the purpose of lifting the valves and sluices in connection with the reservoir.

BELFAST FIRE BRIGADE.

The following description was kindly prepared by Mr. James Munce, Assistant Surveyor.

In 1892 the staff of the fire brigade was composed of six permanent men, and twenty-nine auxiliaries who gave their services when called upon. The horses were hired by contract, and stabled on the premises; but being frequently changed they could not be expected to acquire much intelligence. The urgent necessity for an improvement in the brigade is shown by the increase in the number of buildings. In 1892 the number of buildings erected was 2,212, and the valuation of the city was £737,816, whilst in 1895 the valuation had increased to £844,714.

The new station is situated in Chichester Street, in the rear of the Town Hall, and comprises dwellings for twenty-five men, with laundry and workshops, chief officer's residence, offices, duty room, engine room, gymnasium, quarters for single men, six-horse stable, hose tower, boiler house, and dynamo room. The old buildings have been converted into stables, stores, &c. The buildings are arranged fronting three streets—Chichester Street, Town Hall Street, and Oxford Street—and enclose a drill yard 164 feet by 94 feet. At the left side of the frontage in Chichester Street is the gateway leading to the drill yard. The foundation of the buildings is formed of piles and concrete. Larch piles 40 feet long, 12 inches diameter at head and 8 inches at point, were driven down and sawn off level; a layer of old roofing felt was placed on the bed of the trench, to prevent the concrete from mixing with the sleetch. Portland cement concrete was then filled in to the level of the pile heads. Cross sleepers 12 inches by 6 inches were spiked to the pile heads, and concrete was filled in to the top; then longitudinal sleepers were spiked to these, and concrete was brought up 6 inches above their top edge. On this footings of brickwork in cement were built to the ground line. The superstructure is of perforated brickwork and mortar; solid Annadale bricks were used for the external facing of the engine-house block. There are 49 piles under the tower, and 490 under the remainder of the building.

The engine house occupies the main portion of the Chichester Street front, and is 65 feet long by 35 feet wide, and $16\frac{1}{2}$ feet high to ceiling. It consists of five bays, each with a door $9\frac{1}{4}$ feet wide and 12 feet high, so that an engine can pass out at full gallop. The floor and roof of the gymnasium are carried by steel girders formed of two 16 × 6-inch I joists, with two $\frac{1}{4}$-inch plates riveted on top and bottom flanges. Immediately behind the engine house is the stable. The stalls are so arranged that the centre line of each pair is opposite the centre line of a gate. The doors open into the engine house, and are lined on the stable side with sheet iron and fitted with galvanised rollers at the angles of the jambs, so that a horse rushing out cannot be injured. Over the engine room and duty room are the gymnasium and single men's quarters. The gymnasium is 39 feet by 35 feet and $16\frac{1}{2}$ feet high. It is fitted with bridge ladder, scaling ladder, vaulting horse, parallel bars, climbing ropes, &c. The floor is laid like a ship's deck, and is caulked so as to be perfectly water-tight. It is used as a reading and amusement room by day, and at night as a sleeping room for those on duty. The flat roof of the stables forms a promenade for men off duty.

The tower is situated behind the duty room. It rises 103 feet, and combines a chimney for the boilers, ventilating shaft to stables and engine house &c., and is used for hose-drying and look-out. The hose is made in 50-yard lengths, and can be hung up without a kink. The tower is ascended outside by an iron spiral stair, and has a wrought-iron balcony all round at top, at the level of the electrical testing room. All telephone wires and fire alarms are received in this room, from which they are led down a tube to the switchboard in the duty room.

The quarters for married men are arranged in flats round two sides of the drill yard. Each house is complete in itself, and one room can be taken off any house and added to the adjoining house to suit the number of occupants. All the buildings are covered with flat asphalte roofs, forming a playground for the children. The workshop contains on ground floor a fitter's bench, coachmaker's hearth and anvil, drilling machine, lathe, and 18 horse-power vertical engine. The upper floor is used as a carpentry and painting shop. A travelling crane capable of lifting 10 tons is fixed to raise an engine to the upper floor; and a boiler well is constructed in the ground floor. At one side of the yard is erected a drill balcony 70 feet high. It is of timber, and represents two bays of a six-storey building; and is used for training the men to climb and to use escapes, &c.

The system of electric bells is so arranged that the duty-man can call any individual, or, by turning a lever, the whole staff at once; a sick man or one off duty can be left undisturbed. The station is lighted entirely by electricity generated on the premises. A Lancashire boiler supplies steam not only to the engines for driving the dynamos, but also to a separate engine for the workshops, and hot water to the twenty-five houses, laundry, &c. It is kept at about 40 lbs. pressure during the day, and at 80 lbs. whilst the electric light is turned on to the whole station, that is till 11 p.m. The exhaust steam is used for heating the feed-water pumped into the boiler by a Worthington pump. The consumption of coal is as low as about 40 cwts. per week. The dynamos are driven by two high-speed engines, each of which is capable of developing about 18 horse-power, while the average load is about 10 horse-power for each. The dynamos are on the same bed-plates as the engines, and are driven by belts from the respective fly-wheels. The switchboard is placed in the duty room, where the man on duty has control of the lights, bells, and telephones of the whole station, and of the out-stations as well. The electric current is direct low-tension; and in addition to about 170 incandescent lamps there are two powerful arc-lamps for illuminating the open spaces of the station.

Should an alarm of fire be received at night, the duty-man whilst the telephone is at his ear turns a handle which lights up the bedroom of every man, the engine house and stable, single-men's quarters and gymnasium; instantly the bells ring, the men on duty slip down poles, the first man pulls a cord which releases the stable doors, whereat the horses trot out and get under their harness. This the men secure, while the driver takes his seat; the engineer on seeing all right pulls cords which release the street doors, and the first engine starts off, only about fifteen seconds having elapsed between the receipt of the alarm and the engine starting. Immediately a second engine with men and horses takes the place of that first despatched. The chief officer is Mr. G. W. Parker, who was appointed in 1892.

CORPORATION PUBLIC BATHS.

The following particulars were furnished by the kindness of Mr. R. Graeme-Watt, by whom were designed the three modern sets of Public Baths which have been recently erected in Belfast, namely in Ormeau Avenue, in Templemore Avenue, and on the

Falls Road. The principle on which they have been constructed is practically the same, though the arrangement differs slightly owing to the variation in level and size of the various sites. The general plan of these baths is to have the chimney and boilers as near the centre of the buildings as possible, and for this purpose the first and second-class swimming ponds and the first and second-class slipper-baths are placed symmetrically round the central heating apparatus.

The most recently erected establishment is that on the Falls Road. The sizes of the swimming ponds here are respectively:—second-class 66 feet long by 24 feet wide, and first-class 55 feet long by 24 feet wide. Round each swimming pond is a subway which gives access to all the pipes and connections. There are twenty-three second-class slipper-baths, which are made of concrete composed of cement and marble chippings. This has been found to answer very well for the purpose, as it is easily kept clean and is not liable to chip. The first-class slipper-baths are of porcelain. The walls as far as possible are lined with glazed bricks or glazed tiles, so as to give a bright and clean appearance to the various places. The divisions in the slipper-baths are in the first-class of marble and in the second-class of slate. From experience it has been found desirable to have lavatories connected with the slipper and the swimming baths, so arranged that bathers can pass from one to the other. The laundry is used only for the washing of the establishment. There is a washing machine, which is also for practical purposes a disinfector, inasmuch as the articles being washed can be subjected to a pressure of 10 lbs. per square inch. The cost of this establishment was about £12,000.

In addition to the three establishments referred to, there is also one at Peter's Hill, which was the first enterprise of the kind taken in hand by the Corporation, and dates from 1879. While serving its purpose still and being fairly well patronised, it is not considered specially attractive.

MESSRS. DAVID ALLEN AND SONS, PRINTING WORKS.

For many years this firm has been celebrated for its art posters, of which it has made a specialty, so that a visit to these works will be found interesting, especially for those who have observed the rapid growth and development of this particular industry. When a poster is arranged for, a sketch is first prepared, usually at their London or Manchester house, in both of which is employed a staff of designers including many well-known names. The cost of such a sketch averages from £10 to £20, and sometimes over £100 has been spent in this way. It is then enlarged, outlined in conté crayon, and rubbed down on large litho stones, each of which generally measures about 60 inches by 40 inches, and has a surface grained to a consistency resembling cartridge paper. These are known as black stones. When they are completed, transfers or sets-off are taken, one for each colour required, and are placed on other corresponding stones. The latter when finished are printed in their order, each colour necessitating a separate stone and separate working for each different sheet; a large poster is made up of many sheets. The drawing being previously "fastened" by an etching process, the stone is then conveyed to the printing machine. All the kindred branches of lithography and letterpress printing are carried on by this firm, which, in consequence of the growth of its business, is erecting a new factory at Harrow, near London. In the Belfast house about fifty or sixty artists are employed, making with those in London and Manchester a total of over eighty. More than six million sheets of high-class art posters, made up of more than six hundred varieties, are annually turned out from the Belfast works alone. There are no less than twelve machines for printing sheets of 60 inches by 40 inches, which is an exceptionally large size. Over fifty parcels of theatrical printing are despatched every night by steamer, many of which are for shipment to distant countries.

ANNADALE BRICK WORKS, ORMEAU ROAD.

The machinery in these works, which occupy about 50 acres on the banks of the river Lagan, was laid down by the late Mr. William Fitzpatrick in 1879, though bricks have been made on the ground upwards of fifty years. In 1888 the works were taken over by the present proprietors. The goods manufactured comprise common and selected bricks, perforated, facing, and ornamental bricks, chimney tops, flower pots, ridge tiles, and all kinds of terra-cotta work.

There are at present two brick-making machines, each capable of turning out upwards of 20,000 bricks per day; and several presses, which are each capable of producing 2,000 best facing bricks per day; also several pug mills, and pan and other smaller machines, for use in the various departments. The machinery is specially designed for the clay, and with the steam boilers was made by Messrs. Victor Coates and Co. of Belfast. It is driven by a compound high-pressure condensing engine, with fly-wheel of nearly 20 feet diameter; steam is supplied by two 30-foot Lancashire double-flued boilers, working at about 65 lbs. pressure per square inch.

For drying the bricks, special sheds have been constructed. One of the kilns is of circular shape, containing twenty-four chambers; it is built on the Hoffman principle, and is capable of holding 500,000 bricks. The works employ upwards of 140 persons.

BELFAST ROPEWORK, CONNSWATER.

These works were established in 1876, and are situated in close proximity to the shipbuilding yards, and on the banks of the Connswater river communicating with the harbour. In the stores is a great quantity of raw material, in the shape of bales of hemp and hundreds of barrels of Russian tar. There are ten engines with rope-driving, which transmit about 2,000 horse-power for driving the machinery in the works; most of them are compound surface-condensing, supplied with the latest improvements. Complete arrangements are made by way of precaution against fire; in addition to a range of fire mains from the town supply, there are always in readiness buckets, extincteurs, hose, and steam fire-engines.

Strength and uniformity of make are the principal qualities necessary in ropes and twines. The raw material here used comes from Russia, Italy, India, the Philippine Islands, Yucatan, and New Zealand. The manila is made up in small hanks, and the Russian hemp is in bundles of 14 lbs.; these are packed into bales of 2½ to 5 cwts. After being carefully sorted and picked over by girls, the fibres are taken to the hackling room, where the process is similar to that employed in the preparation of flax. Hand roughing and machine hackling are both used. By the machine process the hemp is carried over rows of pins, which comb it out and lay all the fibres perfectly straight. After hackling, the hemp is placed upon spreading frames, on which a continuous thin band or sliver is formed. This is then taken to the drawing and roving frames, where it undergoes a slight twisting; and the bobbins of roving are taken to the spinning machinery.

Both the wet and dry spinning processes are used, the former principally for fine yarns. After spinning, the yarn is removed to large tanks in another room, to undergo tarring, which assists in the preservation of the rope. The yarn is slowly fed from a circular frame into the boiling tar, and as it emerges is drawn between large iron rollers, which press out superfluous liquid. After being thoroughly dried, the tarred yarn is taken to the rope-walk to be twisted into strands, which are fastened to the hooks of machines called "travellers." These recede on tram lines from a stationary "fore-turn" or twisting head. On each traveller there are about a dozen hooks, and large and small ropes can be made on one machine. A quantity of fishing-lines are still made by hand on the old plan.

Cords made from harsh or extra fibrous material have to undergo a scouring process prior to being sized and polished. The machines take from twenty to thirty separate twines at a time, which have been twisted upon bobbins, and are placed in front of the machine. Any loose fibres which may be adhering are then removed by passing over carding rollers before the twines enter the sizing troughs. After leaving the troughs, the cords pass between two rollers, by which the superfluous sizing is squeezed out. Thence the cords go over a large steam-heated cylinder, whereby a beautiful gloss is imparted to them; and they are then made up into balls.

Special plaiting machines are used for making cords for window sashes, to resist the wear and tear caused by friction. Binder twine for self-binding reaping machines now forms a large manufacture. The range of goods here produced comprises every description of rope, from the largest cable down to the finest yacht-cordage.

Three years after commencing, the firm employed nearly 300 workpeople; now the number exceeds 2,000, with an office staff of about 80 clerks. The managing director is Mr. W. H. Smiles, son of Dr. Samuel Smiles.

BROOKFIELD LINEN CO.

This business was commenced in 1851, and was formed into a limited company in 1866. Since its formation the company has built a second weaving factory, and has now 1,400 looms and 29,000 flax-spinning spindles in operation, besides extensive beetling, finishing, and dyeing works. Spacious offices and warehouses are occupied in Donegall Street, where the different classes of goods are made up and despatched to the home and foreign markets. The company also carries stock in New York, Toronto, Berlin, Paris, Melbourne, and Sydney, and has its agents in all the principal continental and foreign markets. The number of persons employed at all the establishments amounts to 2,600.

MESSRS. CANTRELL AND COCHRANE, AERATED AND MINERAL WATER MANUFACTORY.

The works of this firm were established by Dr. Cantrell in Belfast in 1852, and were situated in Bank Lane. Frequent extensions of the premises were made, until it was found necessary to remove to the present extensive buildings in Victoria Square.

About this time a partnership was entered into with Sir Henry Cochrane of Dublin, who is now the sole proprietor of the two establishments in Dublin and Belfast. The works in Victoria Square stand on what used to be the site of the Town Hall, and portions of this building now serve as counting-house and stores. A well was sunk at a cost of £2,000, and at a depth of 116 feet an abundant supply of water from the Cromac spring was obtained. The supply is practically unlimited, about 18,000 gallons a day being pumped into an enormous slate cistern at the top of the premises. Before reaching this receptacle it undergoes a careful and final process of purification by being passed through a bed of sand and charcoal.

The charging of Cromac water with gas generated from the action of sulphuric acid upon carbonates is the first stage after the pure water has been stored in the slate tank, which is covered with a glass lid, as a security against contamination. The gas is repeatedly washed to obtain absolute purity, and is stored in gas-holders, whence it is drawn as required, a pressure of from 160 to 180 lbs. per square inch being used to impregnate the water. The syrups for the various products are prepared in slate, porcelain, or glass vessels, in order to prevent the formation of chemical deposits. In the bottling room are a number of continuous double-action soda-water machines, driven by overhead belting. Connected with them is a slate cistern of iced water, and everything is so arranged that the processes of gas generation, charging, and bottling are continuous. To this room the bottles are conveyed down an inclined plane from the room in which they have previously been cleansed by steeping in hot water, brushing inside and out, and rinsing in pure cold water.

There are two modes of bottling—by hand and by machine. In the hand process, the bottler sits in front of a machine; the bottle to be filled is placed beneath the mouth of the feeding-tube; the cork is inserted and pressed nearly home; and the requisite quantity of syrup is admitted into a glass gauge by the action of a treadle, and is then forced into the bottle by the aerated water. The atmospheric air is next exhausted, the bottle quite filled, the cork driven home and wired. In another part of the factory, the bottling is effected by automatic rotary bottling-machines. The machine is fed by one man with bottles and corks, the air being exhausted from the bottles as the apparatus revolves. During the revolution the bottles are syruped, filled with aerated water, corked, and delivered upon an endless band, whence boys pick them off and wire them. By the hand process one man generally bottles twenty dozen per hour, but by machine six times that number can be accomplished. In full-working summer days about 60,000 bottles are turned out per day. For sending abroad, the bottles are doubly wired, wrapped in paper, and packed in barrels with straw. Amongst the various mineral waters produced here and at the Dublin factory are club soda, club ale, club kola, seltzer, lithia and potass waters, ginger ale, lemonade, sparkling Montserrat lime-juice, &c. The number of men employed in Belfast and at the Dublin factory is 500.

MESSRS. VICTOR COATES AND CO., LAGAN FOUNDRY AND ENGINE WORKS, AND PRINCES DOCK BOILER WORKS.

These works were established about 1791. The foundry and the boiler works are two distinct establishments about a mile apart, each having its own managers and foremen.

The Lagan Foundry is situated on the east bank of the river Lagan, close by the Albert Bridge; and includes machine shops and foundry, with commercial offices, drawing offices, pattern shops, stores, and other departments, all lighted by electricity. The main building is a lofty erection divided into several bays, each about 50 or 60 feet wide by 160 to 280 feet long. The pattern shop, occupying two of these bays, contains eight or ten benches, and the usual wood-working tools. The adjoining bay is occupied as an erecting shop, and is spanned by a 6-ton overhead traveller, designed and made on the premises. The bay devoted to the machine shop is 320 feet long by 65 feet wide. Running along its whole length is a commodious gallery, in which the lighter class of work is done. An overhead traveller capable of lifting 39 tons spans the bay, and traverses it from end to end. The ground floor contains a full equipment of powerful tools, including several large horizontal drills, boring tools, and a face-plate lathe by Messrs. Thomas Shanks and Son, capable of taking in any diameter up to 15 feet. There is also a pit for turning fly-wheels up to 30 feet diameter.

The turning shop, about 100 feet long by 50 feet wide, adjoins the machine shop. It is equipped with a large number of capstan and other lathes, and with drills and other tools; the shafting and work of a smaller character are done here, and are conveniently handled by a number of small jib-cranes. The smithy is 120 feet long by 50 feet wide, and contains eight fires, two steam-hammers, and the usual tools.

The foundry and moulding shop occupy a separate block of buildings. In the yard are powerful sheer-legs and hoist for breaking up the large pieces of scrap into sizes suitable for the cupola. The foundry is a rectangular building 150 feet long by 85 feet wide, divided into two bays 50 feet and 35 feet wide; one side is devoted to the lighter class of castings, and the other to the heavier. Two overhead travellers span the separate bays, which are also lighted by electricity. Gearing is moulded by wheel-moulding machines.

The Princes Dock Boiler Works are close to the harbour, and entirely under cover; they occupy an area of 250 feet by 170 feet, alongside the dock. The building is divided into four bays, the first of which is spanned by a 6-ton overhead traveller, running the whole length. Plates, angles, &c., are here marked off, and passed on to the next stage. A number of heavy tools are in use; and a portion of the shop is fitted up with lathes and other machine-tools, for dealing with breakdowns and steamship repairs. In the second bay is a plate-heating furnace, large enough to take in plates up to 10 feet wide by 20 feet long; also steam-hammers and plate-bending tools, and a new shell-drilling machine with eleven drills of most improved design, capable of drilling two boilers a week. The third bay is devoted to riveting, which is done by hydraulic machinery wherever possible. The fourth bay contains finished work, and special machinery for flanging Adamson flues. The whole of the works are lighted by electricity, for which the necessary apparatus is situated in the second bay; the dynamo is driven by ropes. The engines for driving the machinery and the dynamo were made by the firm.

Besides steam engines and boilers, the work turned out includes machinery for bleaching and finishing works, for distilleries and breweries, tobacco manufactories, flour mills, soap making, brick making, manure manufacturing, felt and tar works, pork curing, salt manufacturing, railway plant, cranes, pumps, refrigerators, and air compressors. The two works together occupy six acres, and give employment to 500 men.

MESSRS. COMBE, BARBOUR, AND COMBE, FALLS FOUNDRY.

These works were commenced in 1845 for the manufacture of machinery for preparing, spinning, and twisting flax; and occupy an area of five acres, the covered floor area being over 230,000 square feet. They have steadily increased in size and power of production, and their present output includes all the machines required for preparing, spinning, and twisting flax, hemp, jute, manila, sisal, and other similar fibres, ranging from the finest yarns that are used in the manufacture of lace to the coarsest yarns for twines and ropes; laying and cabling machinery; also steam engines of all sizes, single, compound, and triple-expansion; shafting, and all millwright and fire-proof work; as well as all the accessory machines and special tools required in mills and factories. It was in these works that rope-driving originated (Proceedings 1876, page 392); and the first pair of rope pulleys made for main driving purposes over thirty years ago are still at work here. The power is supplied by six boilers, and three condensing and eleven non-condensing engines. The number of men employed is about 1,700.

MESSRS. DUNVILLE AND CO., ROYAL IRISH WHISKY DISTILLERIES.

Although this business dates back to 1808, the present distillery was not erected till 1869, at which time the site it occupies as well as the surrounding district was green fields, and the part now covered by the bonded warehouses was a sheet of water, in some parts 15 feet deep. The distillery comprises several blocks of buildings, built principally of the perforated brick peculiar to Belfast. The octagonal chimney stalk rises to a height of 150 feet, and for the first 60 feet is built with an inner lining of fire-brick, with an air-space between this and the outer structure. Iron hoops were put round the chimney about ten years ago to strengthen it, after an explosion in the air-space, which had been built without provision for ventilation.

Facing the entrance are three Lancashire steam boilers, each 30 feet long by 7½ feet diameter, the flues being fitted with Galloway tubes. They supply steam to the engines and for the various requirements of the distillery, including the heating of the water used for the mashing. In the main flue is placed one of Green's economisers, through which the feed water is supplied to the boilers at a temperature ranging from 250° to 315° Fahr. The higher heat is obtained in the earlier part of the week, when the economiser has the benefit of the waste heat from the pot stills, as well as from the boilers.

Behind the boiler-house are the engine-house and grinding mill. A condensing beam-engine of 150 indicated horse-power, made by Messrs. Victor Coates and Co., supplies the principal motive power. There is also a high-pressure horizontal engine in connection with the still house, as well as several combined engines and pumps for feeding the boilers and for pumping the spent wash in the feeding-stuffs department. The grinding mill contains four pairs of millstones, each 4½ feet diameter, driven at a speed of 140 revolutions per minute, and kept running night and day in order to supply the quantity of grist required for mashing. From the mill the grist is conveyed by an elevator and screw to the grist room, where it falls into large heaps, no sacks being used.

On the left of the entrance is the granary, which with the sheds attached to it is capable of holding 240,000 bushels of grain. Abutting on the granary is the grain kiln and the malt deposit room. Behind the granary and separated from it by a yard 20 feet wide is the malt-house, four storeys high, the roof of which is a wrought-iron tank about 112 feet long by 85 feet wide. This tank has a capacity of over a quarter of a million gallons, and the main object of its erection was to ensure a good supply of water in case of fire. Two kilns for drying malt are attached to the malt-house; and next to the latter is the mash-house, containing three mash tuns, of which the largest is 29 feet diameter by 8 feet deep, having a capacity of over 30,000 gallons. Grist is passed into the various mash tuns through Steel's mashers. All the pumping in this house is done by a rotary pump, driven at from 600 to 700 revolutions per minute, which raises 1,000 gallons per minute to a height of 40 feet. The cooling of the wort is effected by two large refrigerators. Close by is the tun room, containing sixteen fermenting wash-backs ranging in size from 27,000 to 50,000 gallons.

The still-house, situated to the right of the main entrance and near the engine and boiler-house, is in communication with the mash-house. Here there are three pot-stills, holding together about 30,000 gallons, made by Miller of Dublin, with the necessary adjuncts of wash chargers, refrigerators, and receivers for the low wines, feints, and whisky; also the glass safes, through which the various distillates pass. From the still-house the finished whisky is run into vats in the adjoining spirit store, where the final operation of filling into the sherry and other casks takes place.

The principal warehouses for storing and maturing the whisky are situated about a mile from the distillery, in Adelaide and Alfred Streets; and there are also two warehouses adjoining the distillery, which hold about 10,000 butts. The total floor space of the warehouses is over 260,000 square feet, or nearly 6 acres. Between the distilleries and the warehouses a government staff of two supervisors and twenty officers are constantly employed. About

60,000 gallons of whisky can be produced weekly. A very large sum is paid annually in excise duty, an example of which is shown in the payment of over £50,000 in one sum on 1st July 1895, when the spirit duty was reduced. A large proportion of the trade is done under bond, that is, the whisky is sent—without duty being paid in Belfast—to the various crown warehouses all over the kingdom, where the excise duty is ultimately paid. A sum of about £1,500,000 finds its way into the government exchequer before the yearly product of these distilleries passes into consumption. The number of men employed in the distilleries and warehouses amounts to 650.

MESSRS. WILLIAM EWART AND SON, CRUMLIN ROAD LINEN MILLS.

These works embrace the complete manufacture of linen. The flax and hemp spinning mills are in Crumlin Road, and at Mountain Mill, Ligoniel. The power-loom weaving factories are also situated in Crumlin Road and in Bedford Street. The branch of bleaching and dyeing is carried on at Glenbank, Ballysillan. The number of persons employed in the whole of these establishments is 4,500.

MESSRS. GUNNING AND CAMPBELLS, FINE-YARN SPINNING WORKS.

These works are arranged for spinning especially fine numbers of flax yarn by the wet process. For this particular class of yarn it is desirable that the machinery should run with the most perfect regularity; and with this object a set of triple-expansion high-speed engines by Messrs. Willans and Robinson have recently been erected, indicating about 400 horse-power and working with steam at 200 lbs. pressure per square inch, supplied by Lancashire boilers. The latter were specially constructed from the designs of Mr. A. Basil Wilson. The number of workpeople employed is 550.

HARLAND AND WOLFF, SHIPBUILDING AND ENGINEERING WORKS, QUEEN'S ISLAND.

The rise and progress of this concern have taken place in a country which has to import all its supplies of coal and iron. The vessels which have here been turned out are now to be found on every sea, although only a little over forty years have yet elapsed since the founder of the business, the late Sir Edward J. Harland, Bart., came to Belfast. After serving his apprenticeship to engineering in the works of Robert Stephenson, Newcastle-on-Tyne, and filling various posts in the engineering and shipbuilding line in the north of England and in Scotland, Sir Edward, then Mr. Harland, became manager to Messrs. Robert Hickson and Co., who had started iron shipbuilding in Belfast on the Queen's Island at the mouth of the river Lagan in 1854, although even previously to that year a good many wooden ships and a few iron vessels had been constructed in the port. In 1858 the business was transferred to Mr. Harland, and a year or two later he took into partnership Mr. G. W. Wolff, who had served his apprenticeship to Messrs. Whitworth of Manchester; the firm has since been carried on under the style of Harland and Wolff, and about 1874 Mr. W. H. Wilson and Mr. W. J. Pirrie (the present Lord Mayor of Belfast) were admitted as partners, both of them being old pupils of the firm. The total number of hands employed in the yard, which in 1858 was only 100, has now reached about 8,000.

Among the large number of vessels which have left these works, first and foremost comes the entire fleet of the White Star line, including the "Teutonic" and "Majestic" of Atlantic fame; these two being subsidised by government were built with a view to their conversion into cruisers in case of emergency, and at short notice can be mounted with heavy guns. Not only the largest steamer built for the White Star line, but the largest vessel afloat is the "Georgic," 10,077 tons gross, completed in 1895, for the North Atlantic cattle trade. Noteworthy among the ships of the same line is the "Gothic," 7,720 tons, recently added to the fleet of steamers engaged in the frozen-meat trade between England and New Zealand, and also magnificently and luxuriously fitted as a passenger vessel.

Other ships have here been built for the Peninsular and Oriental line, the Pacific, the Union (South Africa), the African Steamship, the Johnston, the Harrison, the Atlantic Transport, the Dominion, the Leyland, the Bibby, the Warren, the Brocklebank, the West India and Pacific, the Asiatic, the "Head," the "Lord," and other lines; also for Messrs. Edward Bates and Sons, and numerous other ship-owning companies and firms. Whilst the work done has been principally for the mercantile marine, four gunboats and a torpedo ship have been built for the navy; two cruisers built in H.M. dockyards have been engined; and there is at present in hand the machinery for H.M. battleship "Hannibal," now building at Pembroke.

Various new features in shipbuilding have here been initiated. For example, the long narrow hull has been developed in a series of nine cargo steamers for the Bibby line, which are employed in the Mediterranean trade. The first of these was the "Venetian," 270 feet long by 34 feet beam, still afloat and at work, but now called the "Landana"; at the time of building she was considered very long in proportion to her beam, but nine vessels were built for the same owners, gradually increasing in length, until the last was as much as 91 feet longer than the "Venetian," although still retaining the same breadth of beam. In conjunction with first-class passenger accommodation in the middle of the vessel, the long narrow build was first adopted in the "Oceanic," built about twenty-five years ago for the White Star line; and, although at first looked upon by many with doubts, has brought about a complete revolution of opinion in its favour. Other new features were the low rise of floor, which is now generally adopted, and commonly known as the "Belfast bottom"; the straight stem; the cut-away fore-foot, which has proved its superiority in the handling of vessels over the yacht-shaped bow at one time almost universal. The twin screw is also strongly advocated, and has been fitted in most of the recent vessels built here.

The works cover an area of upwards of 50 acres, Plate 106, and are built to a great extent on piles, as the Queen's Island is "made ground," mainly recovered from swamps and river. The engine and boiler works, situated on the east side of the Queen's Road, were added to the yard in 1880. Prior to that year, the machinery for the steamers here built was supplied by makers in London, Liverpool, Glasgow, and elsewhere, although fitted on board in Belfast; but now the machinery as well as the ship is constructed in the works.

Entering the ship-yard on the west side of the Queen's Road, the time offices, workmen's entrances, and dining rooms are on the left-hand side of the gateway, and the general offices on the right. The drawing office in the centre is a large and handsome room, surmounted by an artistically decorated circular ceiling and lantern, affording abundant light and ventilation. Alterations and additions to the counting-house are in progress, which when finished will render the offices most convenient in every respect. Complete electric-bell communication extends throughout the building, and there is telephonic communication with the various departments in the ship-yard, the engine works, the city telephone exchange, and the post-office, and thereby with the principal cities in England and Scotland. Behind the offices comes the joiners' shop, built a few years ago and equipped with all the necessary tools and labour-saving appliances. Here are also the cabinet-makers' and polishing shops. The saw mill contiguous to the joiners' shop is likewise of recent construction, commodious and arranged on modern lines, with frame and hand saws of the most recent kind, and pneumatic tubes for conveying chips and sawdust from the various shops, and delivering them in front of the boilers; although to a certain extent in use in America, this arrangement is believed to be at present more or less of a novelty in Europe.

The mould loft at the north end of the yard is large and well arranged. The platers' sheds immediately adjoin the river frontage. The methods of bending and shearing steel plates and various sections of angle and channel bars for the different parts of a ship are almost unique; the two sets of plate-bending rolls are so large as to be capable of dealing with plates up to 31 feet long, of any necessary breadth, and 1½ inch thick. The hydraulic keel-plate setting and flanging machine is also a powerful and useful tool, capable of exerting a force of over 2,000 tons in bending steel plates cold. Besides these heavy tools, there is in this department a complete equipment of power-driven shearing and punching machines; five hydraulic riveting machines, carried by cranes for convenient handling; also five pneumatic riveting machines similarly supported; and the other usual appliances. The smiths' shop is equipped with sixty-eight fires, six steam-hammers, and a hydraulic forging press.

The boiler-house, coal stores, general stores; paint, upholsterers', and pattern shops; boat-building shed, wood-drying kiln, &c., are all separate buildings, in convenient positions between the platers' sheds and the main offices and entrance, Plate 106.

There are four powerful travelling cranes in the open yard; and the whole of the works are traversed by a system of narrow-gauge tramway lines aggregating upwards of nine miles in length, for transporting the large quantities of material that have to be dealt with. Steam power for driving the machinery &c. throughout the works is supplied by eight Galloway boilers of 2,000 horse-power in the ship-yard, and by six of the same construction in the engine works.

The large electric-lighting installation comprises engine and dynamos by various makers, including Messrs. Allen, Crompton, Brush Co., Mather and Platt, and Stanley and Davis, besides sixteen machines which have been constructed on the premises. In the ship-yard there are 205 arc lamps, each absorbing 45 volts and 22 ampères of current. A large number of these are hung on poles from 70 to 90 feet high, placed in different parts of the works. The main offices are lit by 300 incandescent lamps, some of which are of the "sunbeam" pattern; a storage battery is also used when the dynamos are not running. In the engine works there are 200 arc lamps distributed throughout the shops. The total candle-power in the entire establishment amounts to about 410,000. Electric light is also largely used on board the various ships when finishing.

At the north end of the yard there are five slips, and six at the south or Abercorn Basin end, all of which are at present occupied by vessels in course of construction. Among the larger ships on the stocks or finishing may be mentioned the "China" for the Peninsular and Oriental Co., and several for the White Star line, the Union Co., the Pacific Co., the Hamburg-American Steam Packet Co., and other ship-owners. After a ship is launched at the Queen's Island, she is generally taken to the 60-ton sheers in the Abercorn basin or to the 100-ton crane at the Alexandra jetty. After receiving there her boilers, heavy machinery, masts &c., she is brought round to lie at one of the jetties in the Abercorn basin for finishing, Plate 106.

The Hamilton graving dock lies between the ship-yard and Queen's Road, and is capable of accommodating vessels up to a length of 470 feet. The Alexandra graving dock, measuring 830 feet in length, is available for ships of larger dimensions. In this fine dock the "Scot," belonging to the Union Steam Ship Co., was lately lengthened, being cut in two, pulled asunder 54 feet, and the new portion built into place.

Crossing to the engine works on the east side of Queen's Road, the main entrance is immediately opposite the sheer legs at the Abercorn basin, the time offices and workmen's entrances being situated on the left, while the drawing offices &c., which are tastefully designed and have been recently erected, are on the right. Near to the gateway are the fitting, turning, and erecting shops, where all the most modern machine-tools are to be found, as well as pits for erecting, travelling cranes, &c. In the adjoining smiths' shop there are thirty-five fires, six large steam-hammers, and two steam-olivers. A forge for working up scrap, with hammer, furnace, crane, &c., forms part of the same building as the smiths' shop.

Running parallel with these buildings are the store, fettling shop where castings are dressed and cleaned, and pattern shop. In front of these buildings is the brass foundry, alongside the boilers for supplying steam; and in an L shaped building the iron foundry is arranged, with four cupolas, large drying stoves, and several powerful overhead travelling cranes. The extensive boiler shops are situated alongside the Queen's Road, and are fitted with numerous machines driven by steam and hydraulic power; in each bay are several overhead cranes for lifting heavy weights.

For four years running the Queen's Island Works held the highest place in the world as regards the amount of tonnage launched, and the following are the figures for the last six years:—

Year.	Number of Vessels launched.	Total Tonnage.	Indicated Horse-power.
1890	13	48,626	22,900
1891	13	64,962	34,650
1892	14	68,612	33,650
1893	15	65,660	41,640
1894	13	65,448	41,800
1895	7	58,093	26,800

The falling off in 1895 was due to the unfortunate strike of the engineers. In addition to the engines constructed during last year for vessels launched from the yard, the two White Star steamers "Germanic" and "Doric" also received new boilers and machinery, of 6,500 and 3,200 I.H.P. respectively, making a total of 36,500 I.H.P. for 1895.

The firm is assisted in the commercial department by Mr. Bailey, who has been connected with the establishment since its beginning; and Mr. Carlisle and Mr. Pratten are the respective managers of the ship-yard and the engine works.

MR. GEORGE HORNER, CLONARD FOUNDRY.

These works were established in 1859 by Mr. George Horner for the construction of hackling machines, of which some 2,520 have already been made from his various designs. They are situated in the largest spinning district of the city, and in close proximity to the users of the machines. These comprise single and duplex stripper-rod machines for hemp and the coarse and medium flaxes; single brush-and-doffer machines for the fine flaxes; and giant hackling machines for the various fibres used in their full length in rope and twine making; ending machines, flax cutters, hemp breakers and cutters; and other machines used in connection with hackling. A large trade is also done in castings and general millwright work. The departments comprise a foundry, having a 5-ton travelling crane, two jib cranes of 10 and 5 tons and smaller cranes; hackle-making shop; machinery, turning, fitting and erecting shops, and forge. When in full work they employ about 160 men.

MESSRS. INGLIS AND CO., MACHINE BAKERY.

This business was started in Castle Street, and was moved in 1882 to larger premises in Eliza Street, near to the river, the railway, and the public markets. The buildings cover more than an acre, and have storage capacity for twenty thousand 280-lbs. sacks of flour. Fifty-five ovens of various kinds are in nightly use, and the bake-house appliances are capable of baking 2,000 large sacks of flour per week. Labour-saving machinery is largely employed, from the blending and automatic weighing of the flour to the dividing of the finished dough for baking. At the present time the products, in the shape of bread, cakes, pastry, &c., are to be found in most of the towns and villages within fifty miles of Belfast. The premises are lighted by electricity, and the baking is mainly done during the night. The stables contain 75 horses, and about 300 persons are employed.

MESSRS. McCAW, STEVENSON, AND ORR, LINENHALL PRINTING WORKS.

This printing, publishing, and chromo-lithographic business was established about twenty-three years ago in Arthur Street, whence it was shortly removed to larger premises in Linenhall Street, and again in February 1895 to the present still larger premises at Loopbridge, Castlereagh Road, having a floor area of 126,600 square feet, or nearly 3 acres.

The special work here done consists of high-class chromo-lithography, letterpress printing, bookbinding, &c.; also transparent label printing, now largely used, and "glacier" window decoration. The latest improved machinery is in use in all the departments, and the works are fitted up and arranged for dealing most expeditiously with all kinds of high-class printing. The number of persons employed is very large.

MESSRS. W. A. ROSS AND SONS,
AERATED AND MINERAL WATER MANUFACTORY.

These works, situated in William Street South, were founded in 1879 by Mr. W. A. Ross. They comprise a large and substantial block of buildings, underneath which is an artesian well nearly 250 feet deep, whence is pumped an abundant and unfailing supply of water, almost equal in purity to distilled water and more wholesome. The machinery is of the most effective kind, comprising a number of ingenious and labour-saving machines. The utmost cleanliness is observed in all departments, especially in the syrup room, where all the utensils and apparatus are of glass, crockery, or slate, no metallic appliances being used. In addition to the manufacture of aerated waters and ginger ale, raspberry vinegar is prepared from a special class of berries, grown in the firm's own gardens at Craigavad, County Down. The number of workpeople employed is 150.

THE ULSTER SPINNING CO.,
FALLS MILLS.

These mills, founded in 1833, are situated in Falls Road; and are wholly driven by means of a triple-expansion engine, recently erected by Messrs. Combe, Barbour, and Combe, whose works adjoin. The engine was put in to replace three beam-engines, and the saving effected by the change is over 50 tons of coal per week. The cylinders are 19 inches, 29 inches, and 46 inches diameter, with

3½ feet stroke. The engine is designed for 1,000 indicated horse-power, but at present, running at 80 revolutions per minute, is driving only about 700. The change in the motive power also entailed a considerable change in its distribution, and the whole of the shafts are now driven by ropes instead of by toothed gearing. The power required to drive the engines and shafting has thereby been slightly reduced, thus showing that properly designed ropes do not absorb more power than toothed gear. The number of workpeople employed is 1,219.

MESSRS. MARCUS WARD AND CO., ROYAL ULSTER PRINTING WORKS.

These works were established early in the century for printing, publishing, lithographing, book-binding, and the manufacture of stationery; they were rebuilt in 1874 at Bankmore, not far from the centre of the city. The building fronting the Dublin road is of red brick with terra-cotta insertions; the wide porch with pillars of red polished granite has the royal arms elaborately carved within the gothic arch. The front building is occupied with the sales and order departments, where samples of the various manufactures are on view.

The works extend backwards a considerable distance along the side street, and form an angle with the building which runs parallel to the Dublin road, the ground plan being ⊥-shaped. On the ground floor all the heavy machinery of the letterpress and lithographic printing departments is placed; the large area with its broad glass-roofed side-aisles contains the printing machines arranged in rows, all of the latest and best construction. The work turned out is of the most varied kinds, from the largest pictorial posters to the smaller sheets of elaborately finished Christmas cards, coloured show-cards, trade labels, and commercial printing. The lithographic department occupies one side of the floor space, and letterpress printing the other; on the ground floor is also the stereotyping and electrotyping department.

The entire block of buildings consists of five storeys, all of which are reached by a central fire-proof granite staircase for the workpeople, while a steam lift is used for transferring goods from one department to another. The first floor is occupied by the counting-house, offices, and board-room ; also the artists' department, which consists of one large room, running the entire length of the building and facing the north, and occupied by the artists, designers, illuminators, engravers, lithographers, and die sinkers. At an angle with this room is the drying room for printed work ; and also the compositors' room, situated immediately over the machine room, where the actual printing is done, with which it communicates by separate stairs and by elevator.

On the floors above are carried on book-binding, manufacture and preparation of stationery goods, enamelling, fancy-box making, cardboard making, varnishing, and gelatining ; whilst the making up of Christmas cards and other fine printed work employs a large number of young women all the year round. An extensive business forming an important department of the works is the manufacture and preparation for the British and colonial markets, through their houses in London, New York, and Sydney, of the royal Irish linen and other writing papers. A considerable trade is carried on in publishing literary, artistic, and educational works, and in the manufacture of albums, diaries, leather goods, &c. The works occupy a floor space of about 4½ acres, and give employment to over 800 persons.

MESSRS. WORKMAN, CLARK AND CO., SHIPBUILDING AND ENGINEERING WORKS.

The works of this firm consist of two ship-yards and the engine works. The North Yard at Spencer basin, on the north side of the river Lagan, was started in 1879, and the total tonnage turned out in that year amounted to 600 tons. Now the combined areas of the ship-yards and engine works amount to over 50 acres, and the total launched in 1895 was 43,723 tons, placing these works fourth in the year's list for the United Kingdom. Besides a commodious set of offices, the Spencer Basin yard contains all the most modern tools and appliances for building vessels of the highest class, examples of which can be seen on the slips and at the finishing berth alongside the yard. There is also a large caisson in course of construction for the government.

The South Yard in Queen's Road was acquired in 1893 and contains about 13 acres. It has great facilities for launching, and is conveniently placed as regards the public graving dock and fitting-out berths. The engine works, erected in 1891, consist of pattern shop, smiths' shop and forge, fitting, turning, erecting, and boiler shops; the last is at present undergoing enlargement. In every department the largest and most modern machine-tools have been provided. The erecting shop is of such height that the largest modern marine engines can be erected on the floor, without having recourse to the ordinary engine-shop pit. The number of men employed in the ship-yards and engine works is about 3,500.

YORK STREET FLAX SPINNING AND WEAVING WORKS.

These mills, situated in almost the centre of the city, were founded in 1830 by the late Mr. Andrew Mulholland, from whose son, the late Lord Dunleath, and his partner, Mr. O. B. Graham, they were purchased by the present company in 1864. They were the first works of the kind in Ireland; and having since been increased by the purchase of another flax-spinning mill and a bleach-green, the company are now able to carry on all the manufacturing operations required for converting the raw flax into finished linen.

The works occupy an area of 786 feet length by 221 feet width, or about four acres, extending from York Street on the east to North Queen Street on the west, and from Henry Street on the south to Sussex Street on the north. The central part of the west end, a fire-proof building of eight storeys, occupies a space of 124 feet length by 50 feet width. In it are stored flax, tow, dressed line, brown cloth, &c. The roof forms a cistern, supplying hydrants in the lobbies.

The south wing, 72 feet by 40 feet, has five storeys, and contains hydraulic presses, crane pumps, and gas-engine to drive them. The north wing, 229 feet by 46 feet, has six storeys, and is fireproof. This is the preparing mill. The first storey is used for tow carding and preparing; the second, third, and fourth for flax or line preparing, which includes spreading, drawing, and roving; the fifth storey for machine hackling; and the sixth for hand hackling and sorting. The east end communicates with the spinning mill by stairs and hoists through a building, 26 feet by 16 feet wide, of six storeys, which are used as stores, with the engineers' shop on the first floor.

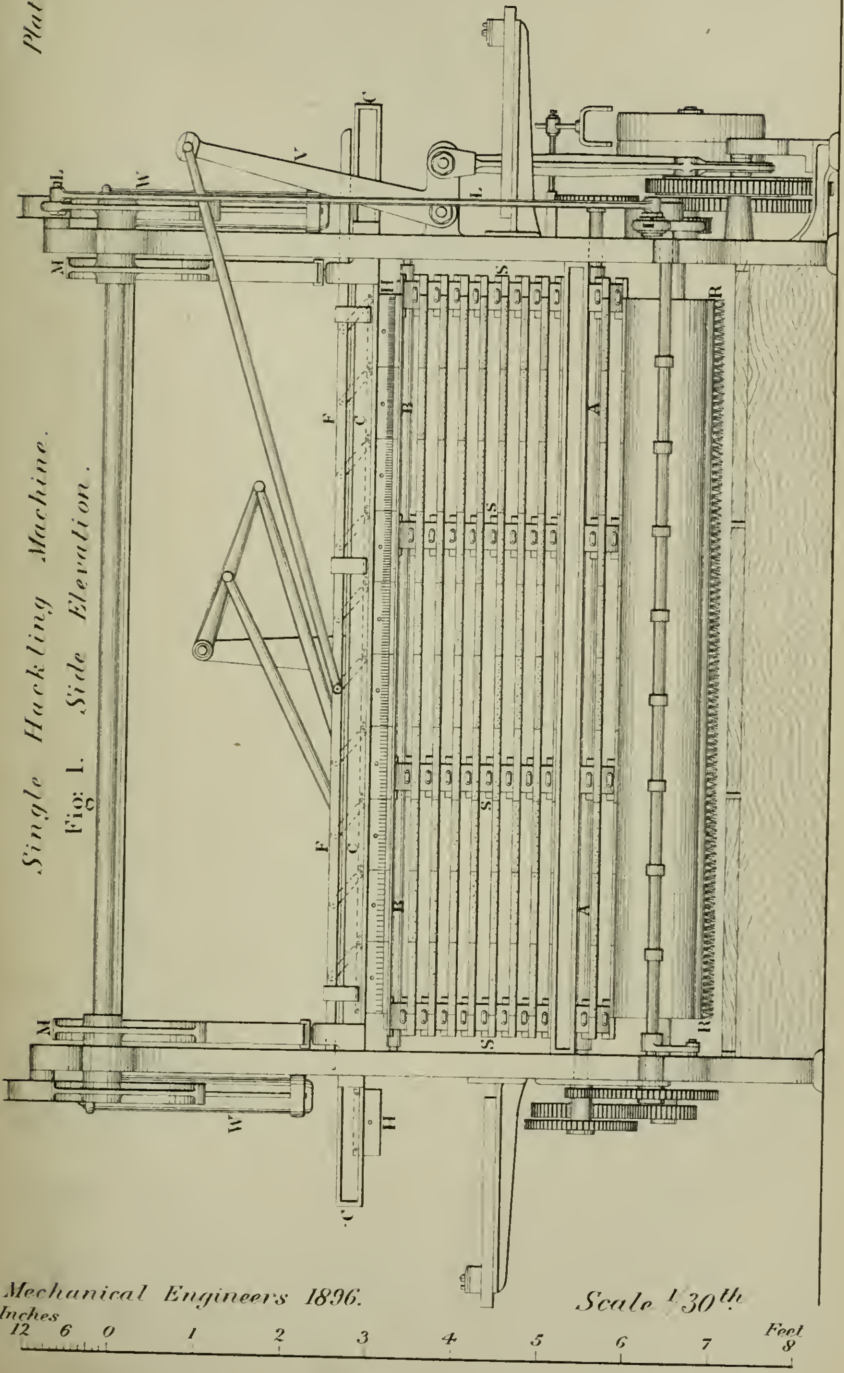
The spinning mill is 221 feet length by 42 feet width, and the first storey is used for hackle-makers' shops, engineers' stores, wood-turning and fluting shop, weaving, beetling, cropping, and lapping rooms. The next four storeys are utilised as wet-spinning rooms, which contain 34,000 spindles; and the sixth is a reeling-room, from which there is a wire tramway to the drying loft on the third floor of the boiler houses.

On the south side are three buildings occupied as offices, sale-rooms, yarn stores, and stock and lapping rooms. In the quadrangle are eight Lancashire boilers and three beam-engines with Corliss valves. One engine, with 35-inch cylinder and 5 feet stroke, making 45 revolutions per minute, drives the preparing mill. The two others, with 35-inch cylinders and 7 feet stroke, making 32 revolutions a minute, drive the spinning mill. For driving the weaving factory and heavy finishing machinery there are four Lancashire boilers supplying steam to two beam-engines, with 38-inch cylinders and 7 feet stroke, which have wrought-iron beams and Corliss valves, and make 29 revolutions per minute. They drive two main shafts direct from the fly-wheel.

At the south-east corner is a five-storey building, in which the first floor is used for weaving, the second for pirn winding, the third for yarn dressing and beaming, the fourth for hank winding, and the fifth floor for dressing. Adjoining is another building with similar accommodation. In an adjacent building the first floor is used as a drawing-in shop and beam stock-room; and the second floor as a cloth-passing room, from which a carrying band conveys cloth 138 feet to cropping machines on the first floor of the spinning mill. The weaving sheds contain 1,000 looms for plain and damask linens. Bleaching is carried on at Muckamore, county Antrim.

The manufactures include fronting linens of different qualities, interlinings, printed linen shirtings, dress linens and lawns, &c., towels, hollands, handkerchiefs, sheetings, damasks, &c., and various goods for the West Indies and Spanish colonies, such as creas, platillas, bretanas, silesias, irlandas, &c. Besides 4,500 regular workpeople employed, large numbers are also engaged in the country in embroidery and fancy work, and also on the bleach-green.

FLAX DRESSING MACHINERY.



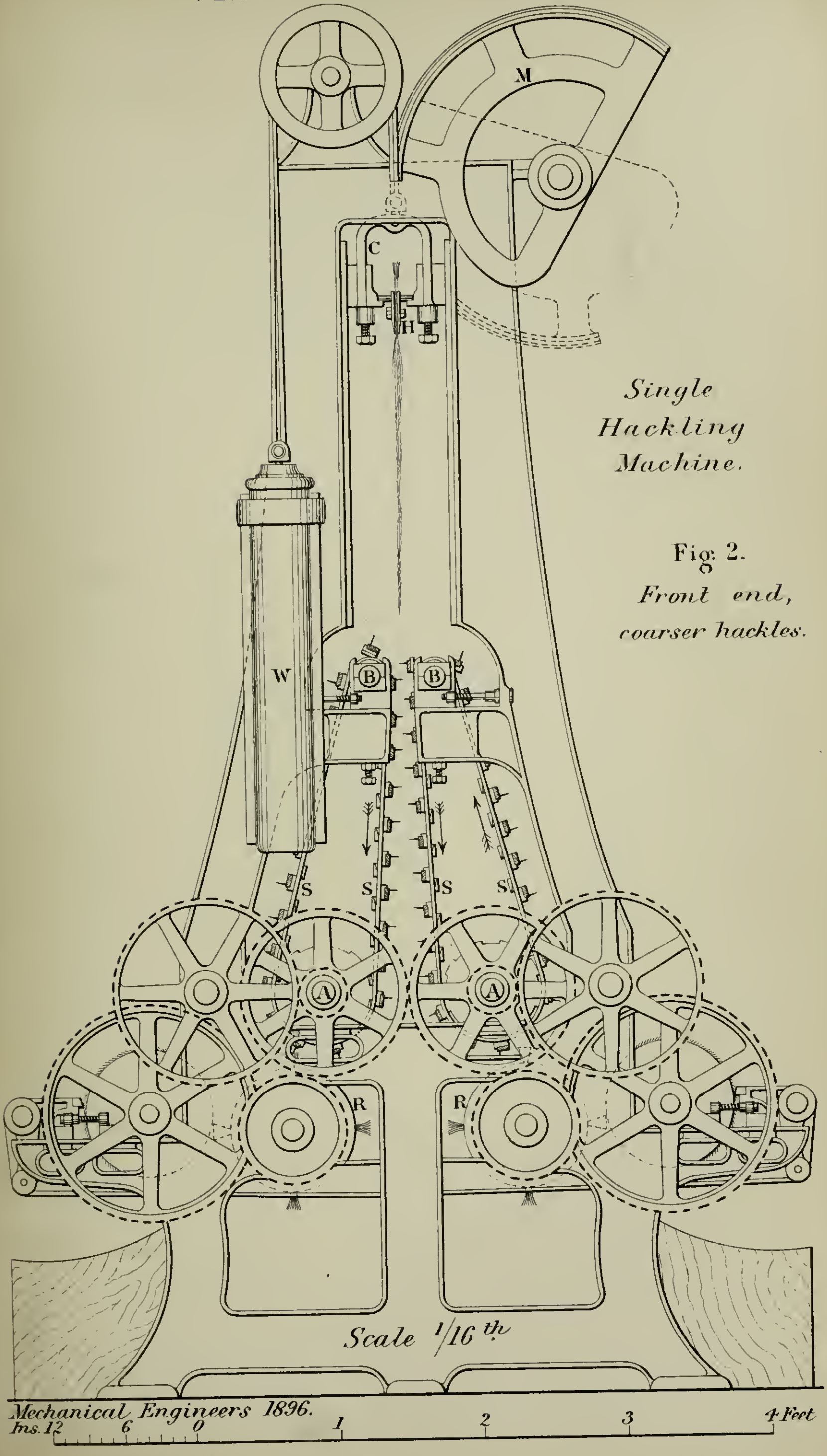
Single Hackling Machine.

Fig. 1. Side Elevation.

Mechanical Engineers 1896.

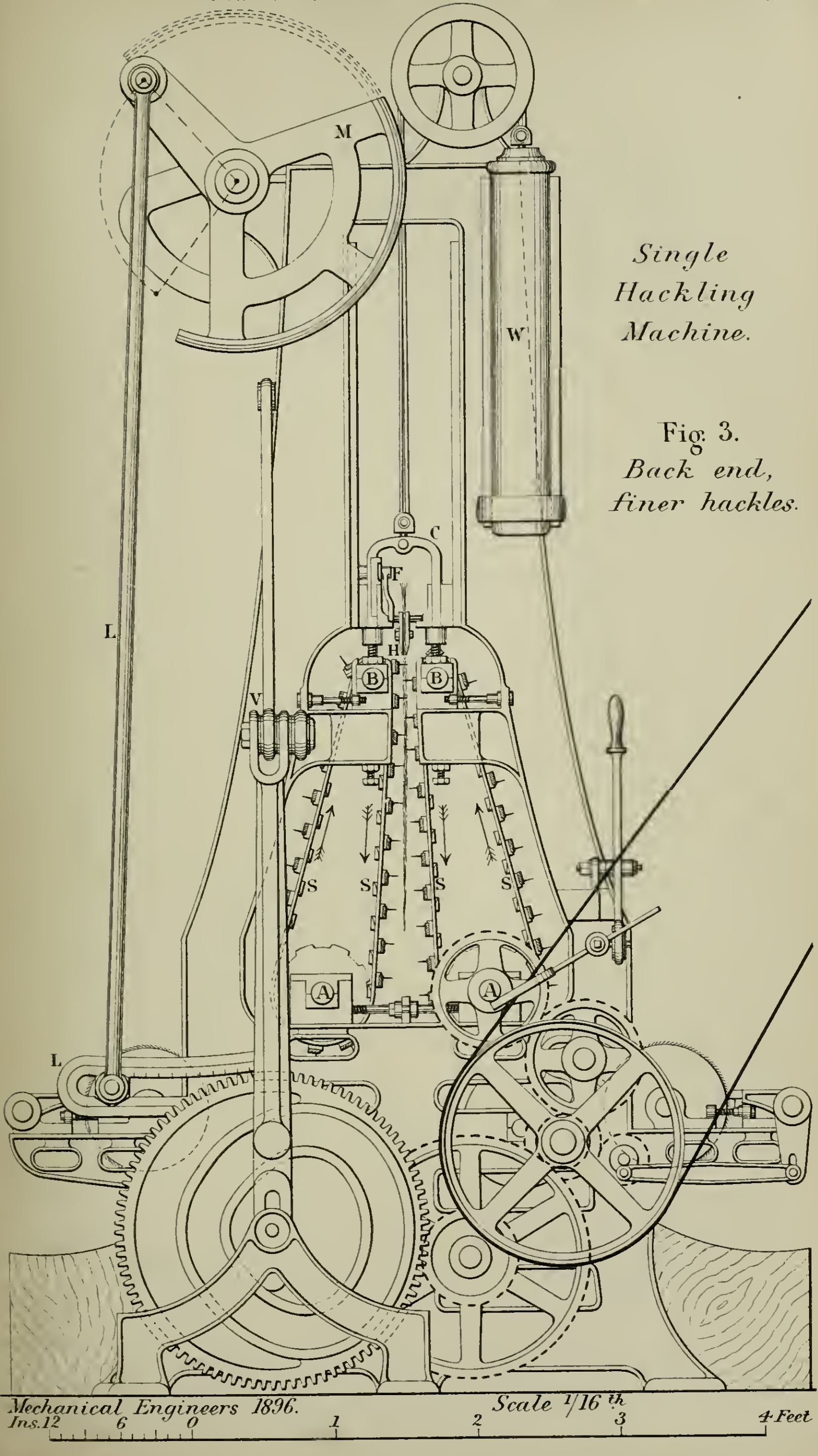
Scale 1/30th.

FLAX DRESSING MACHINERY.



Single Hackling Machine.

Fig. 2.
Front end, coarser hackles.



Single Hackling Machine.

Fig. 3.
Back end, finer hackles.

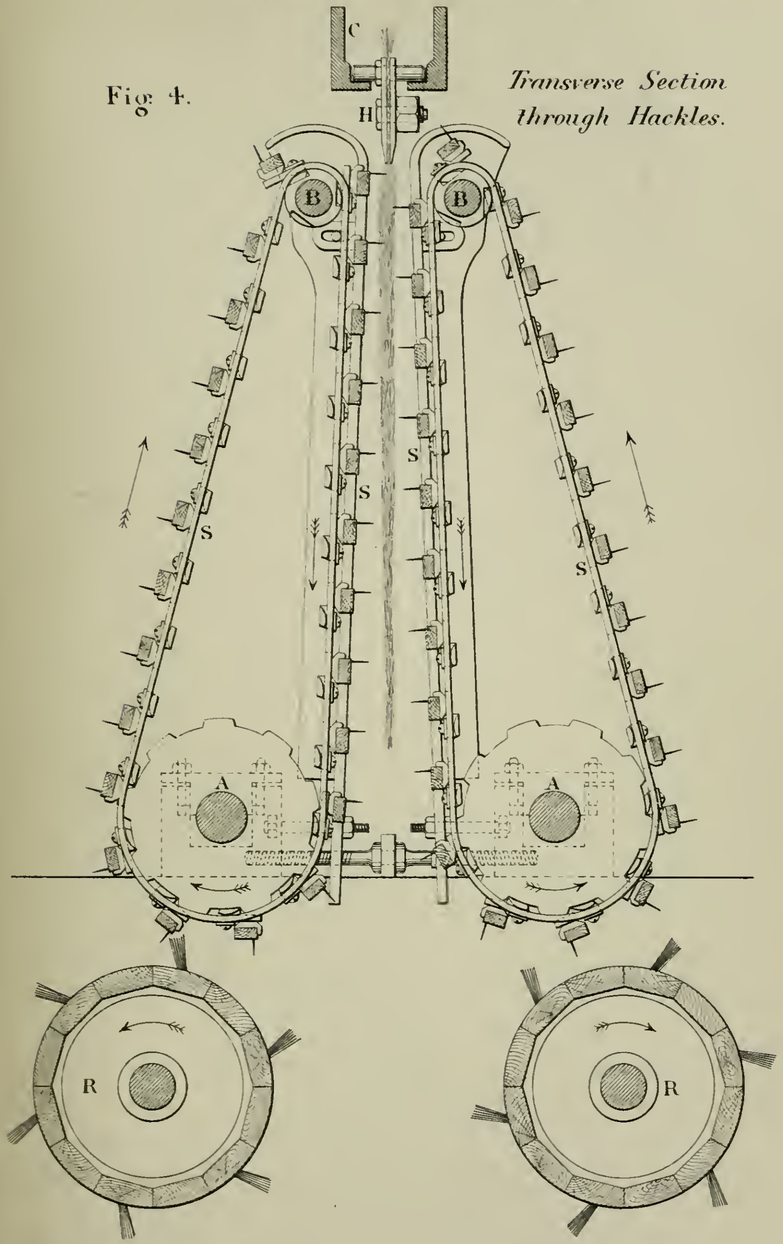
Mechanical Engineers 1896.

Scale 1/16 th

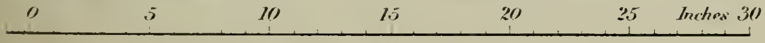
Single Hackling Machine.

Fig. 4.

Transverse Section through Hackles.



Mechanical Engineers 1896. *Scale 1/8th*



FLAX DRESSING MACHINERY.

Hackling Machine.

Up and Down Motion for channel.

Fig: 5.

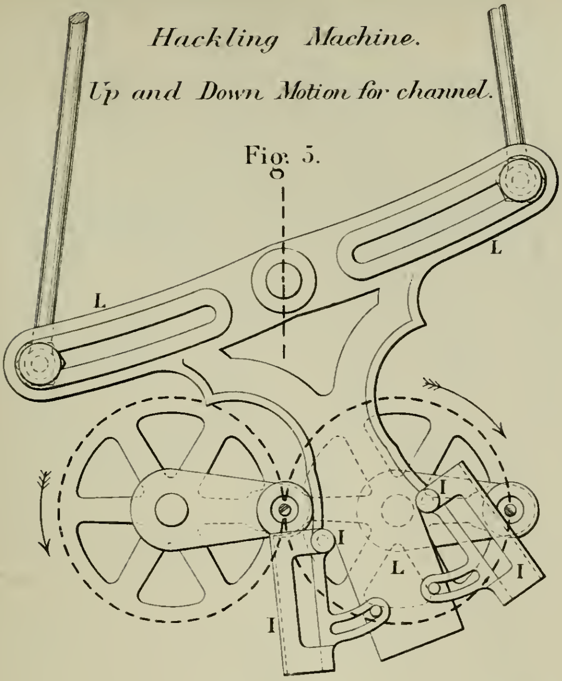
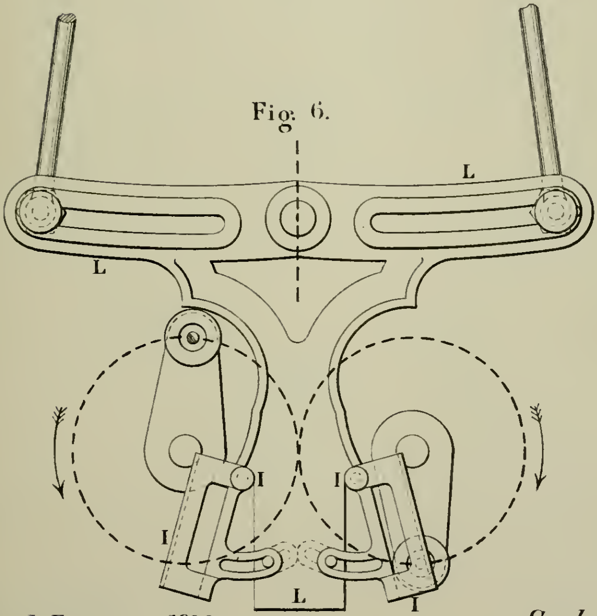


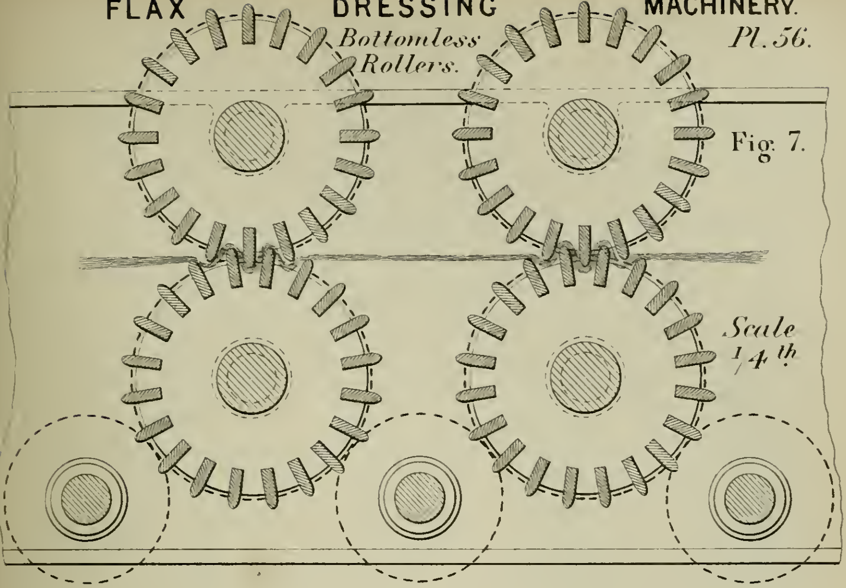
Fig: 6.



Mechanical Engineers 1896.

Scale 1/12th.

10 5 0 10 20 30 *Inches*



Bottomless Rollers.

Fig. 7.

Scale 1/4th

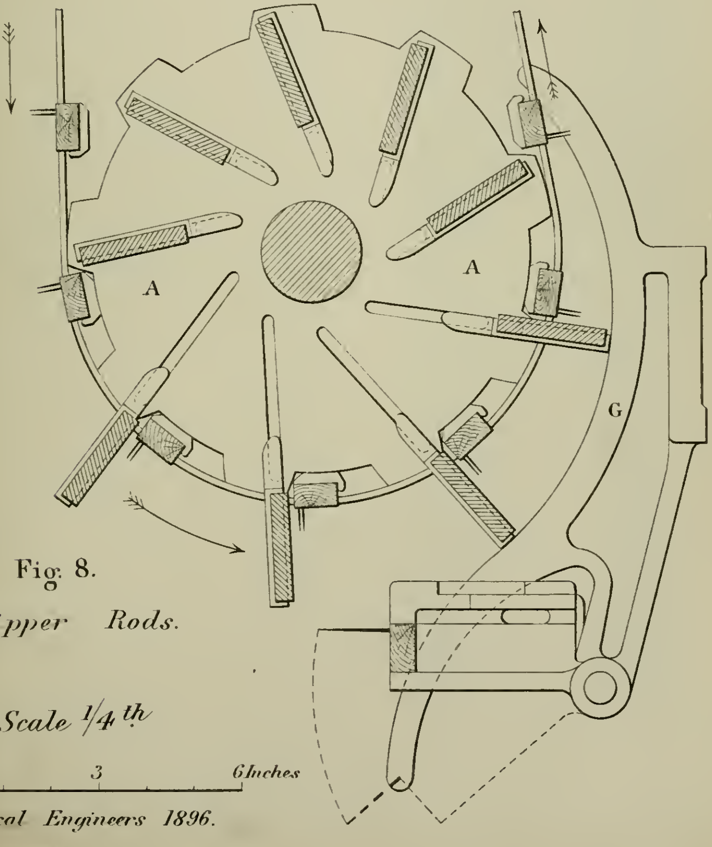


Fig. 8.

Stripper Rods.

Scale 1/4th

0 3 6 Inches

FLAX DRESSING MACHINERY.

Hackles. Scale half full size.

Fig: 9.

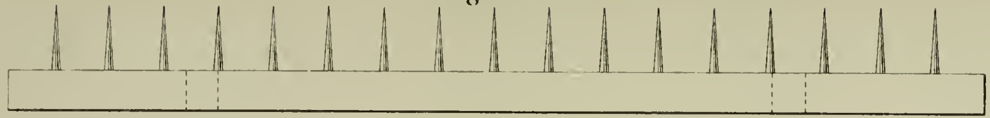


Fig. 10.

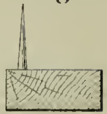


Fig: 11.

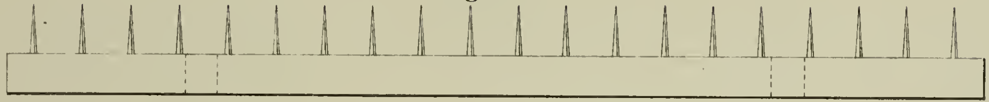


Fig: 12.

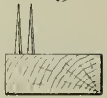


Fig: 13.

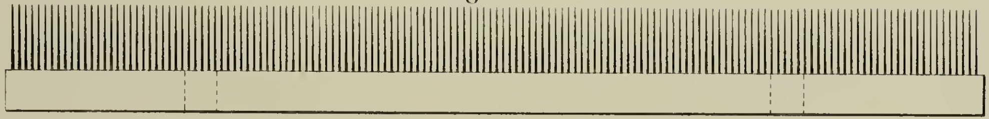


Fig: 14.

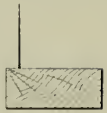


Fig: 15.

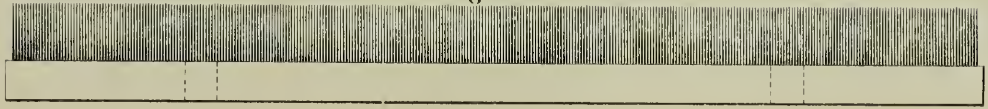


Fig: 16.

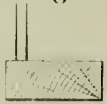


Plate 57.

FLAX DRESSING MACHINERY.

Fig: 17. Grouping of Pins.

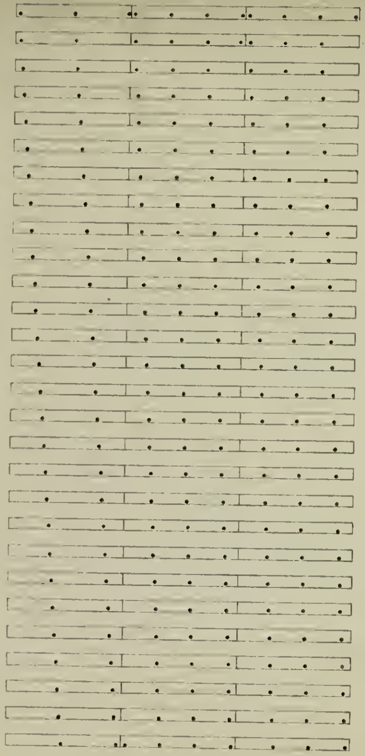


Fig: 18. Grouping of Pins.

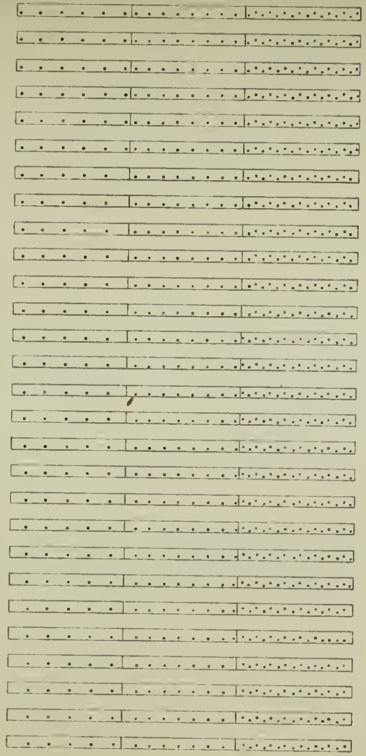
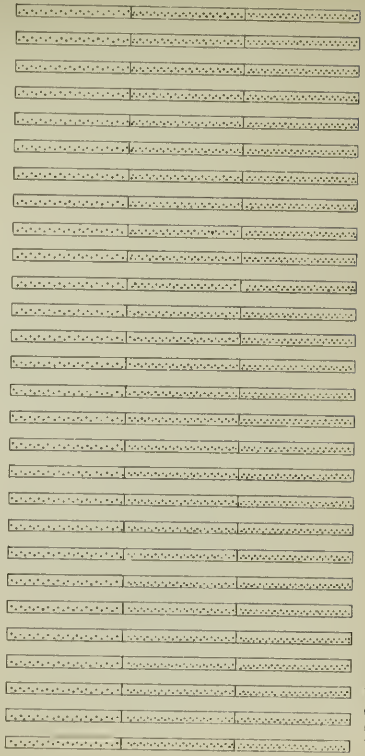


Fig: 19.



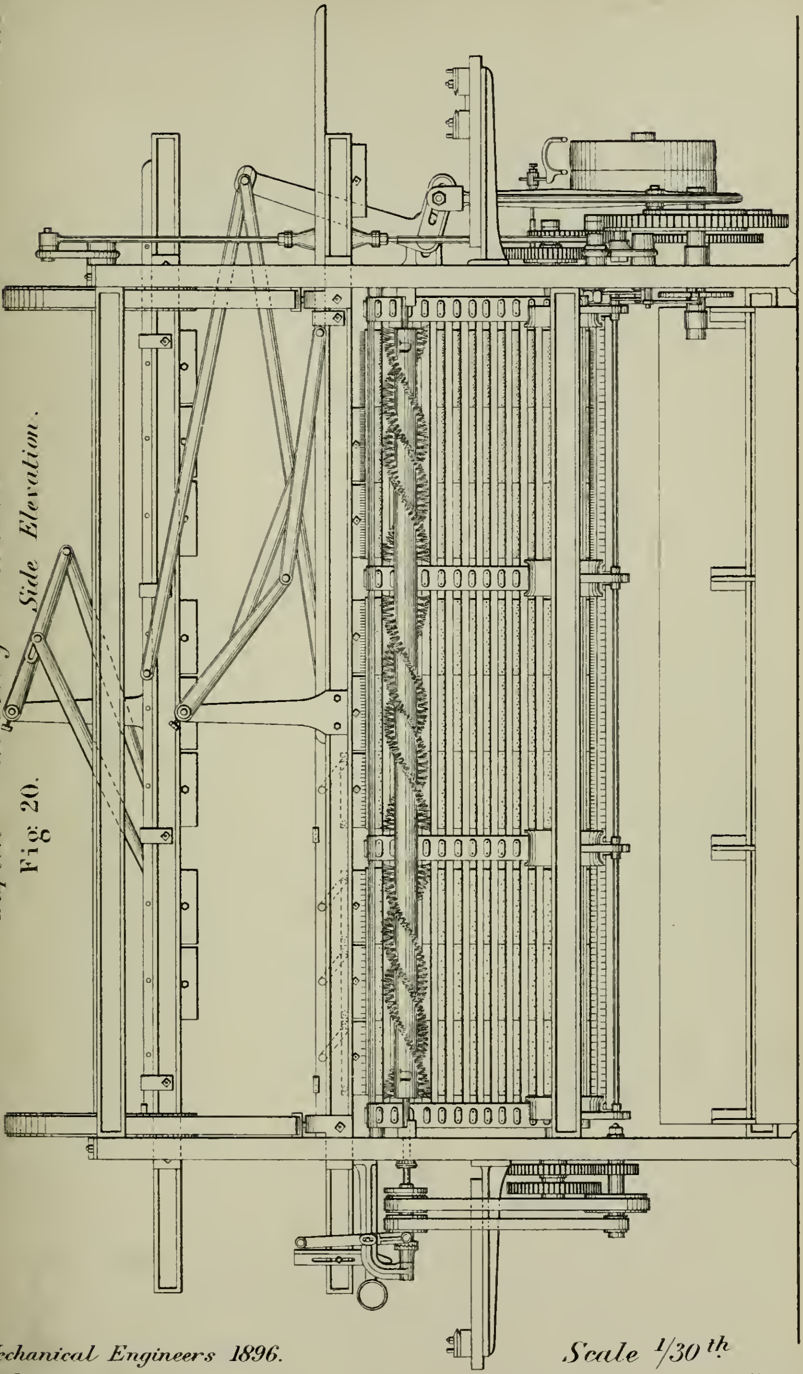
Scale 1/18th.

FLAX DRESSING MACHINERY. *Plate 59.*

Duplex Hackling Machine.

Side Elevation.

Fig. 20.

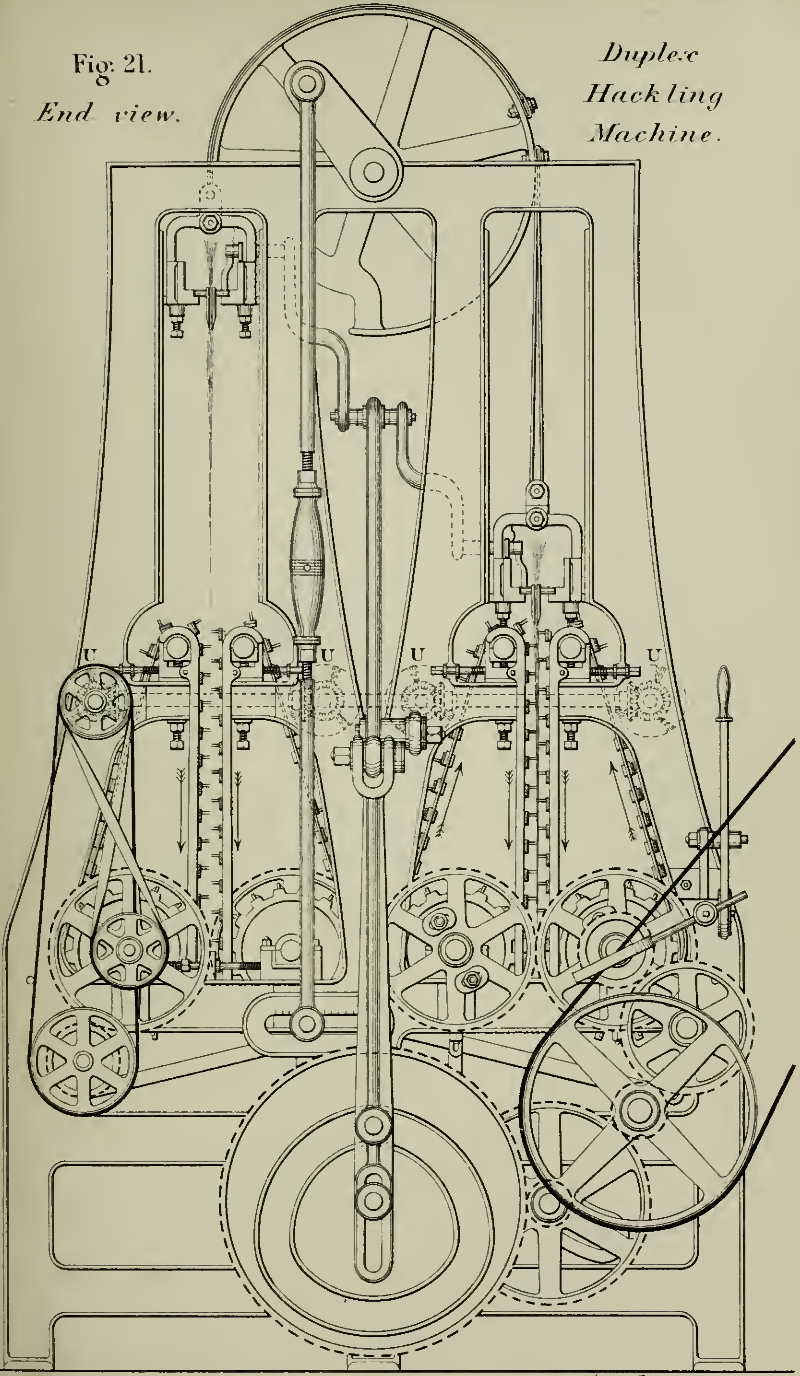


Mechanical Engineers 1896.

Scale 1/30th.

Fig: 21.
End view.

Duplex Hackling Machine.

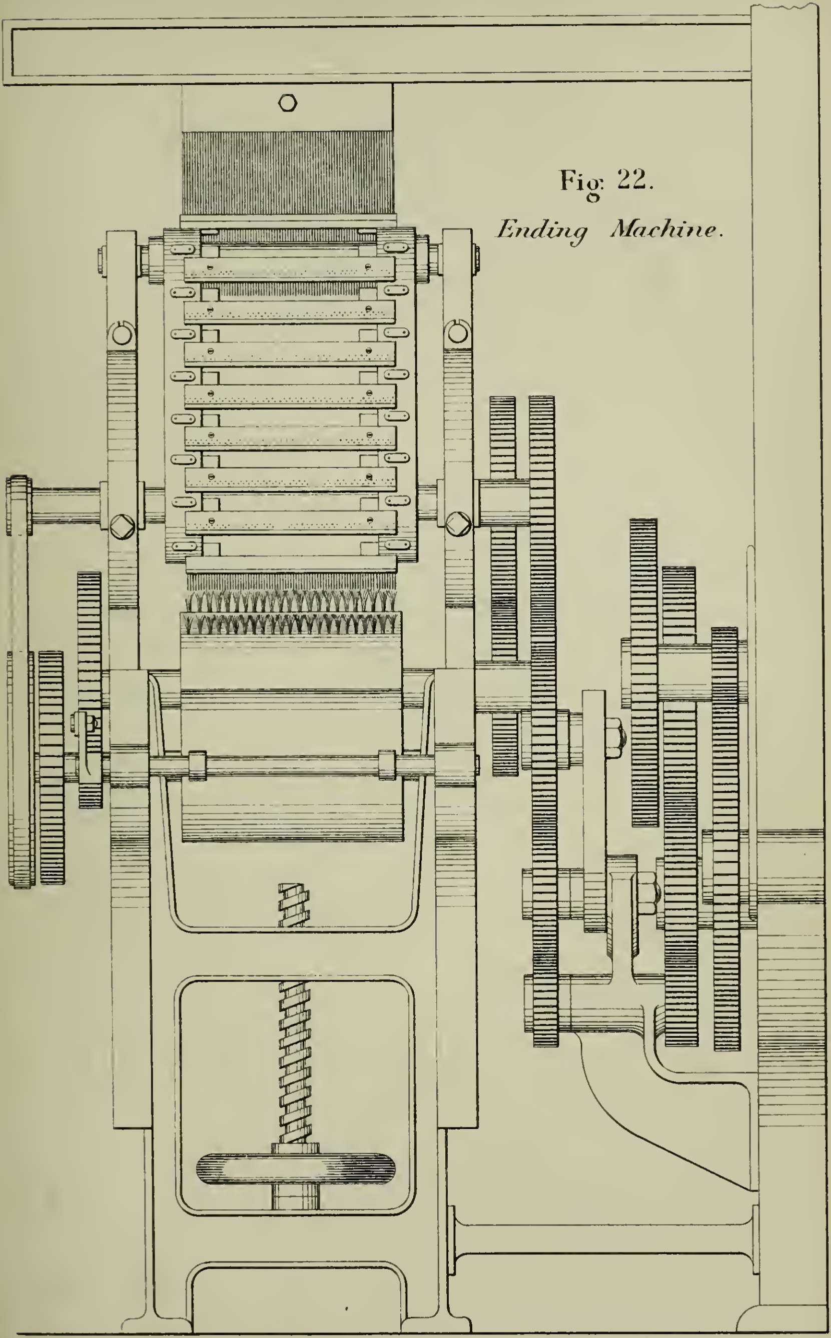


Scale $1/16^{th}$

Ins. 12 6 0 1 2 3 4 Feet

Fig: 22.

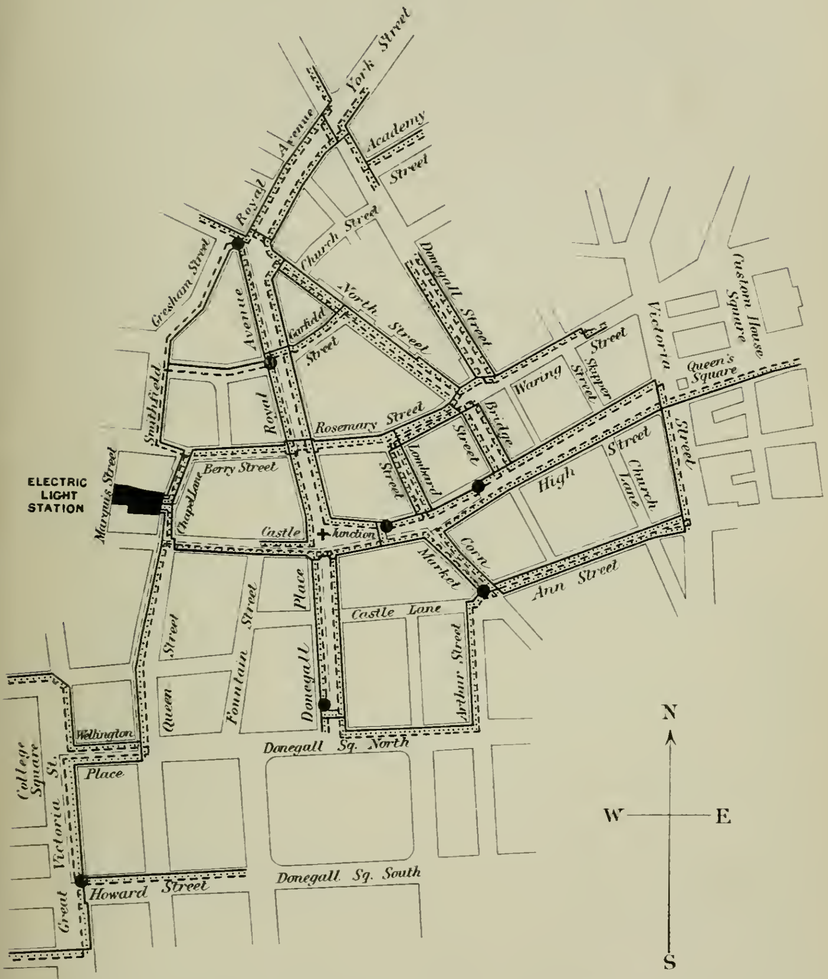
Ending Machine.



Mechanical Engineers 1896.

Scale 1/10th

Fig. 1. *Plan of Mains.*

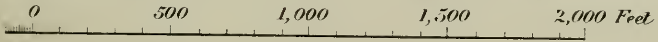


Feeders and Mains, Positive ———— *Negative* - - - - - - - -

Middle wire ····················· *Pilot Wires* – – – – – – – – – –

Feeding Points ● *Castle Junction* +

Mechanical Engineers 1896. *Scale 700 feet to an inch*



BELFAST ELECTRIC LIGHTING.

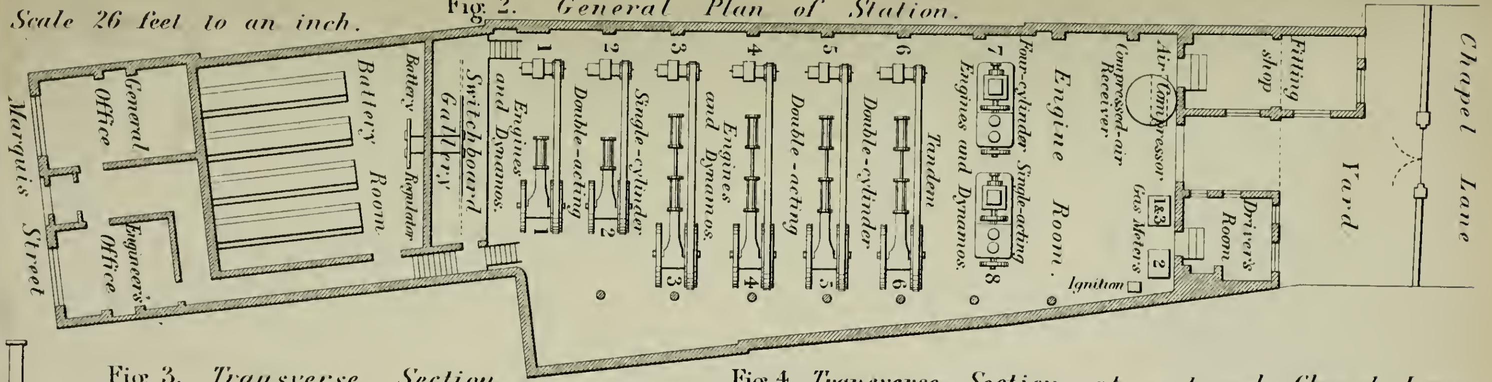


Fig. 2. General Plan of Station.

Scale 26 feet to an inch.

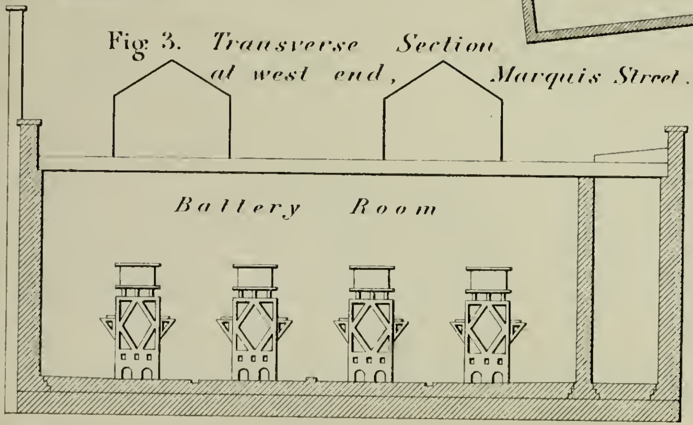


Fig. 3. Transverse Section at west end, Marquis Street.

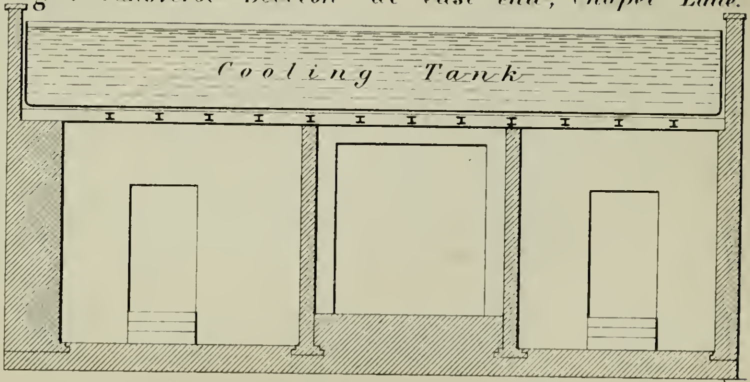


Fig 4. Transverse Section at east end, Chapel Lane.

Scale 10 feet to an inch

BELFAST ELECTRIC LIGHTING.

Switchboard.

Fig. 5. *Section.*

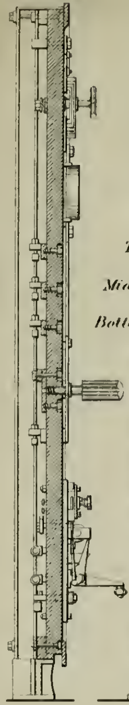
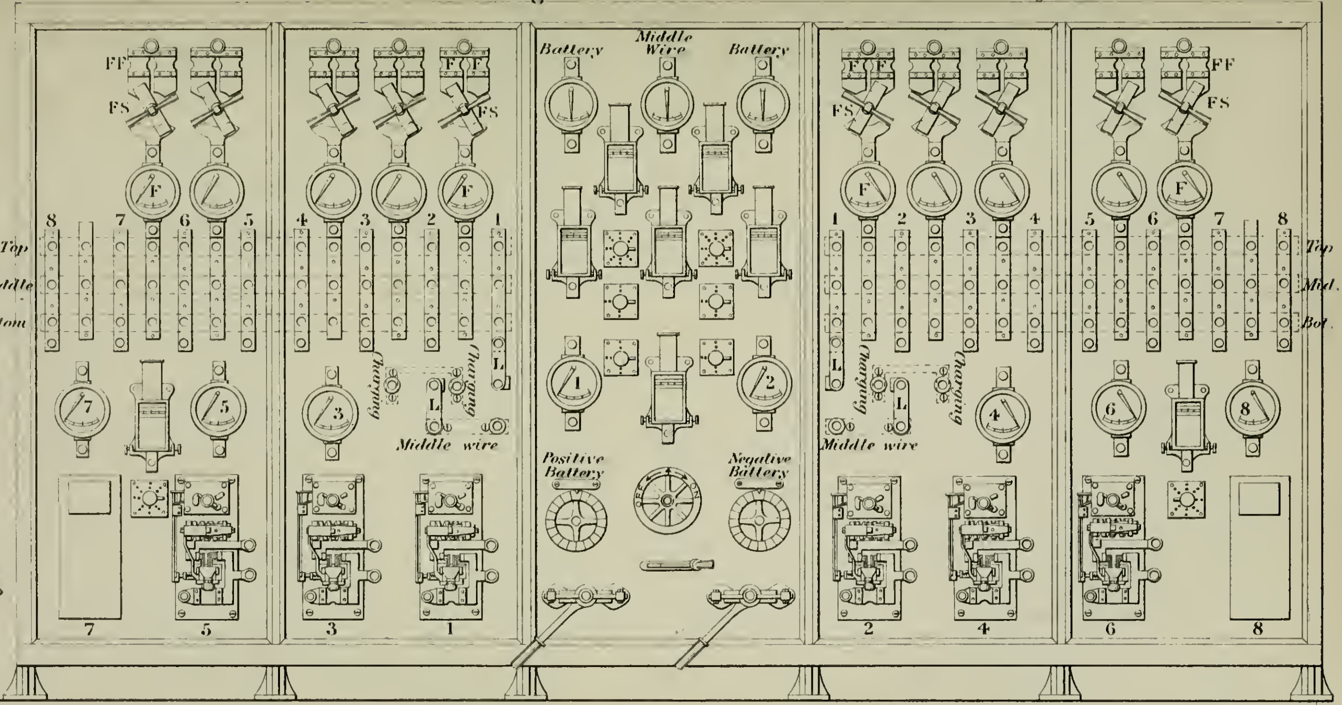


Fig. 6. *Elevation.*

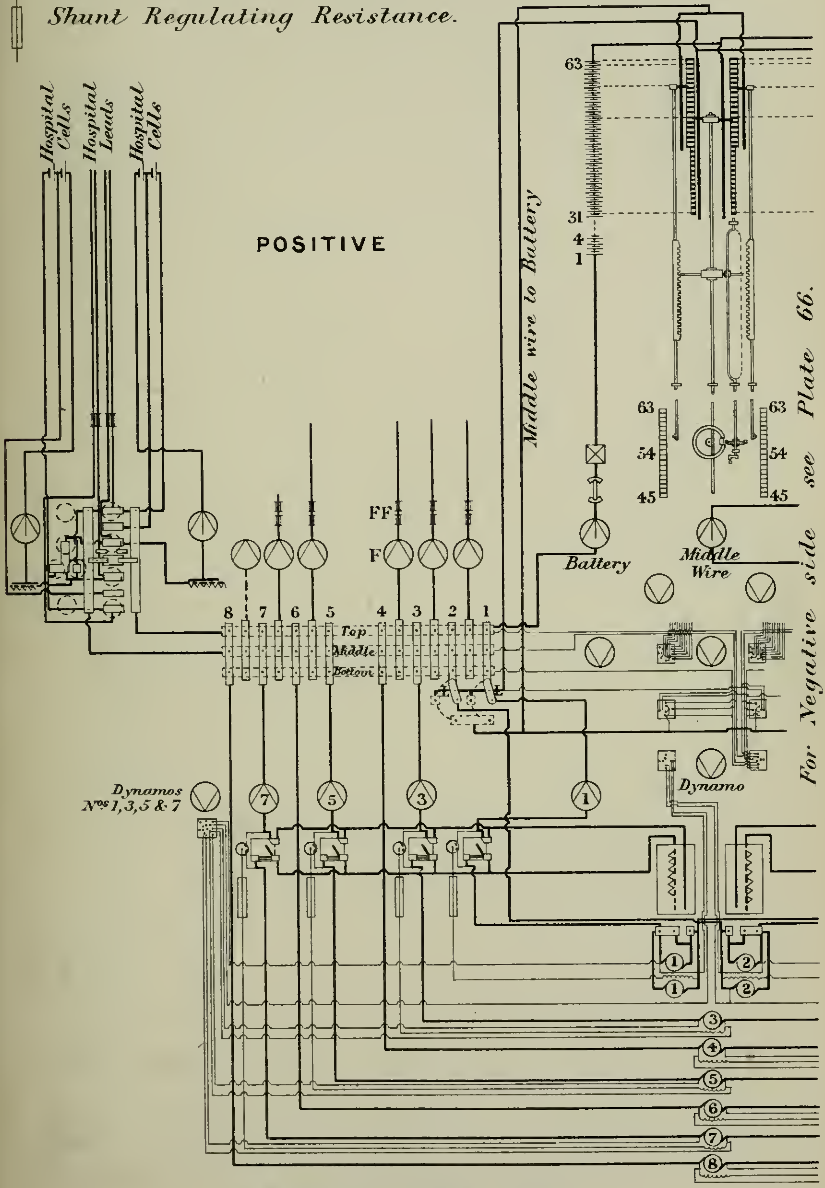


Mechanical Engineers 1896. *Scale 1/25th*

12 Ins. 6 0 1 2 3 4 5 6 7 *Feet* 8

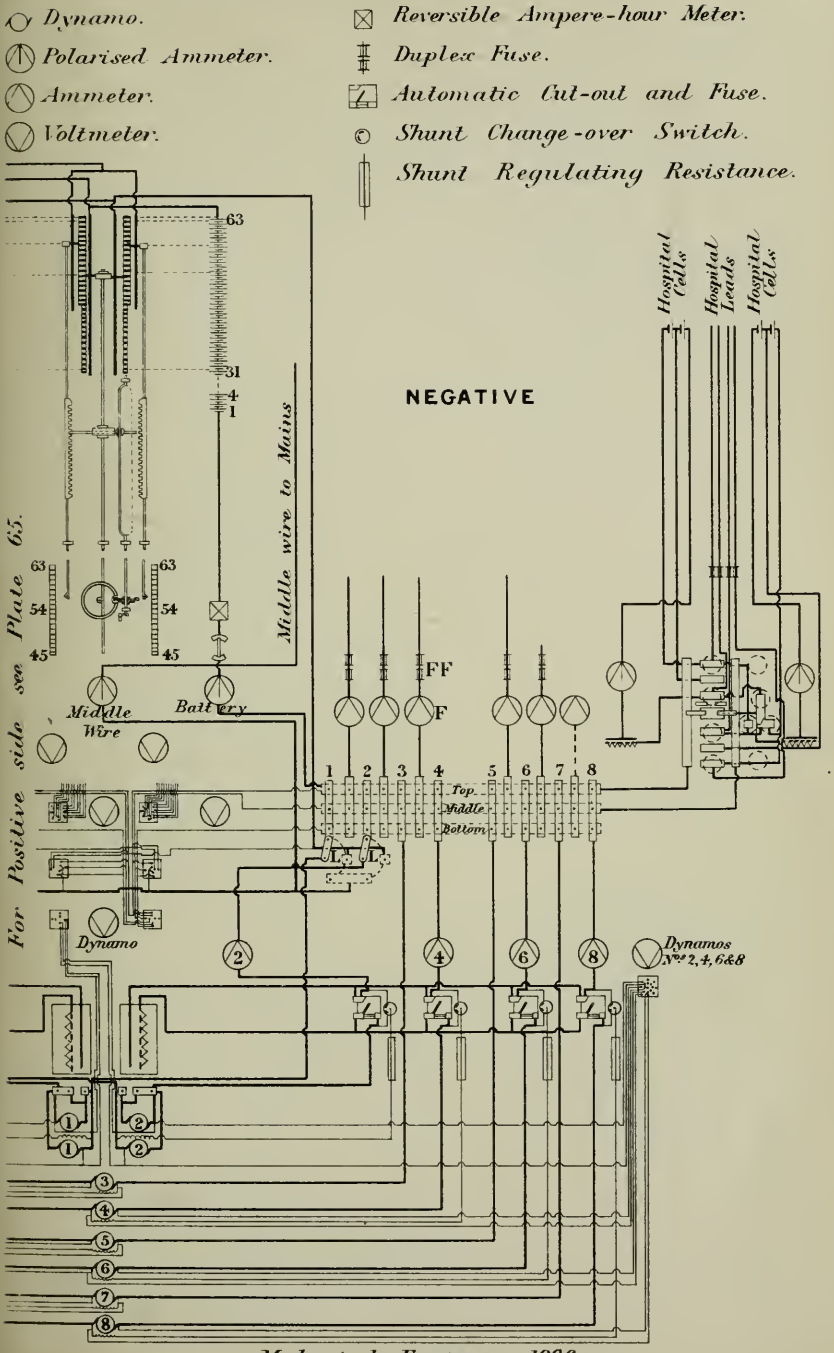
Fig. 7. *Switchboard connections.*

☒ *Reversible Ampere-hour Meter.*
╪ *Duplex Fuse.*
▨ *Automatic Cut-out and Fuse.*
◎ *Shunt Change-over Switch.*
▯ *Shunt Regulating Resistance.*
○ *Dynamo.*
Ⓐ *Polarised Ammeter.*
Ⓐ *Ammeter.*
Ⓥ *Voltmeter.*



For Negative side see Plate 66.

Fig. 8. *Switchboard connections.*



Mechanical Engineers 1896.

BELFAST ELECTRIC LIGHTING.

Plate 67.

Tandem Double-cylinder Double-acting Engine.

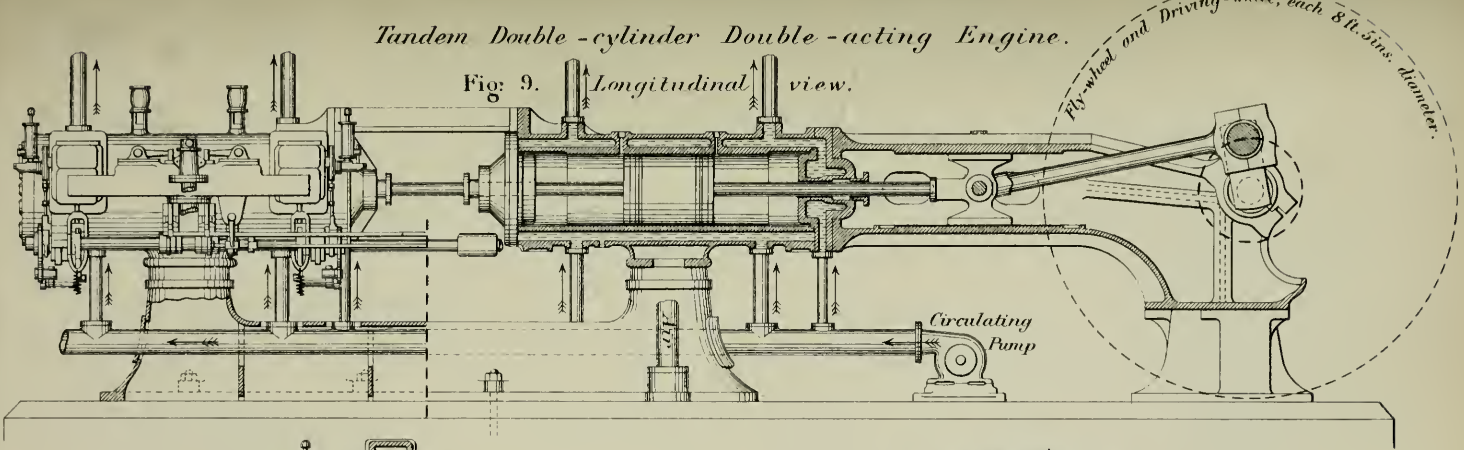


Fig: 9. *Longitudinal view.*

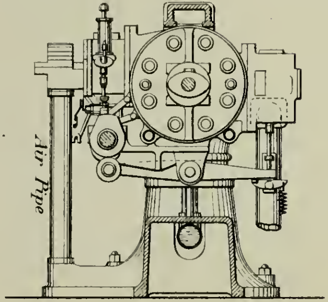


Fig: 10.
End view.

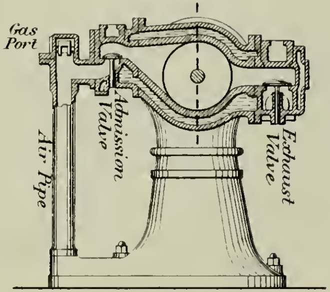


Fig: 11.
Transverse Section.

Scale 1/36th.

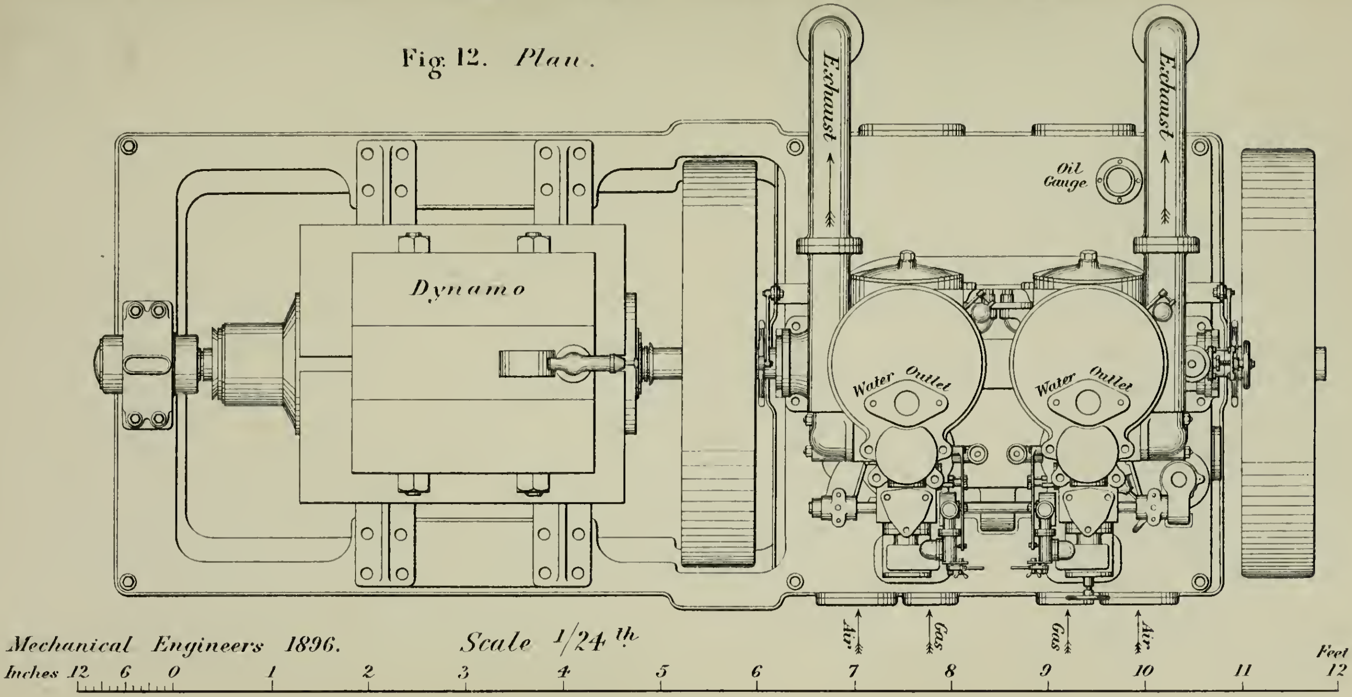
Inches 12 6 0 1 2 3 4 5 6 7 8 9 10 11 12 Feet

Mechanical Engineers 1896.

BELFAST ELECTRIC LIGHTING.

Four-cylinder Single-acting High-speed Engine.

Fig. 12. *Plan.*



Mechanical Engineers 1896.

Scale 1/24th.

BELFAST ELECTRIC LIGHTING.

Four-cylinder Single-acting High-speed Engine.

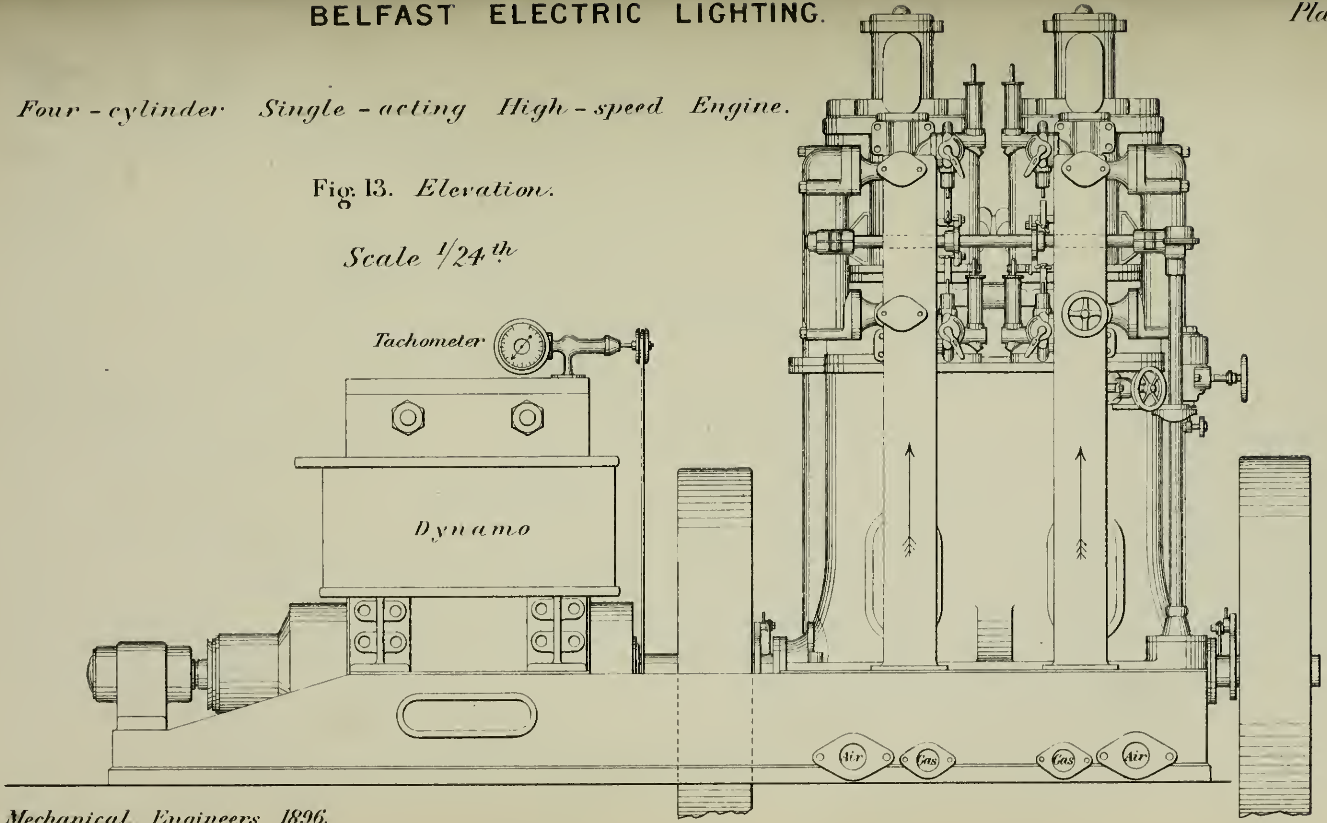


Fig. 13. *Elevation.*

Scale 1/24th.

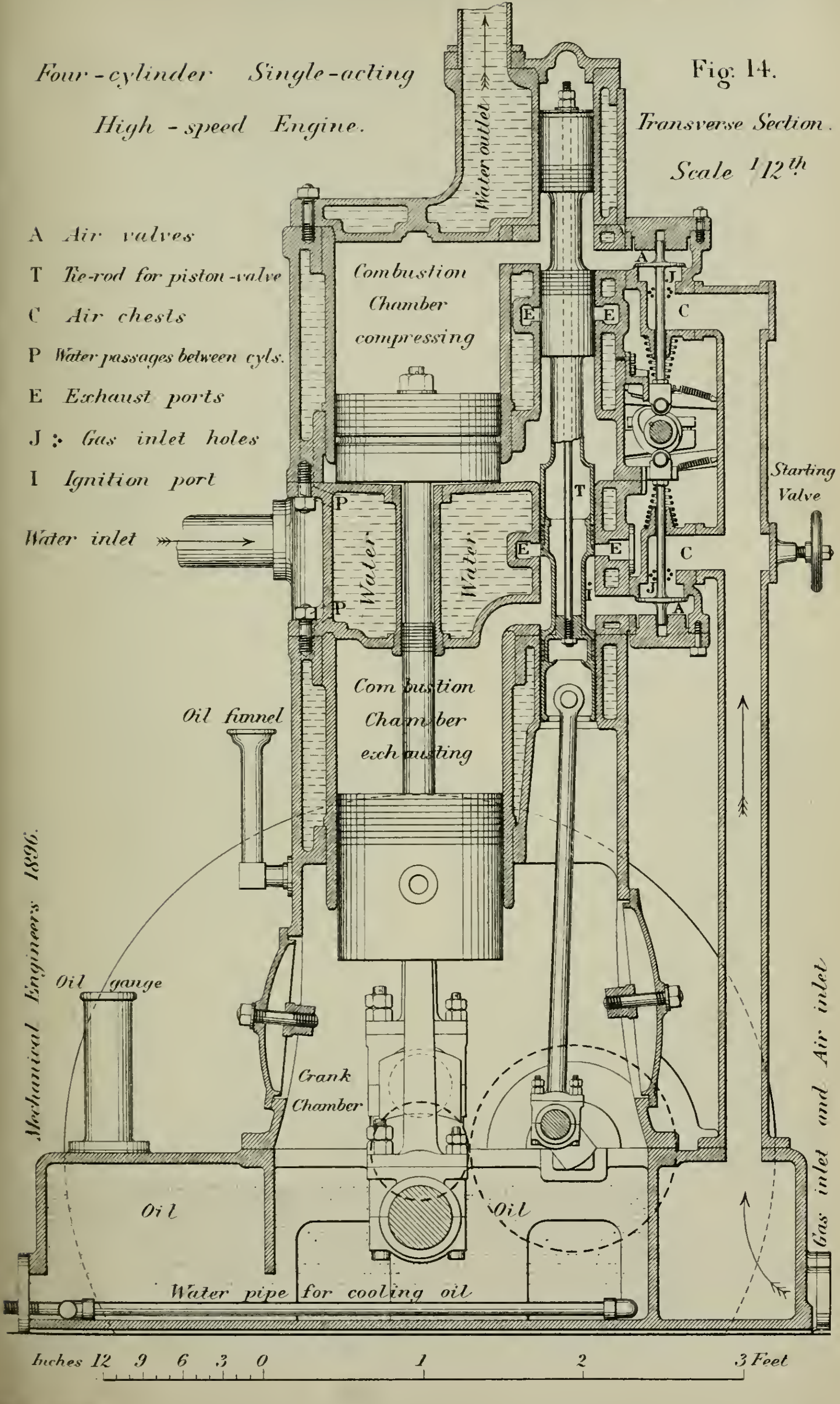
BELFAST ELECTRIC LIGHTING.

Four-cylinder Single-acting High-speed Engine.

Fig. 14.

Transverse Section.

Scale 1/12th



A *Air valves*

T *Tie-rod for piston-valve*

C *Air chests*

P *Water passages between cyls.*

E *Exhaust ports*

J ⁖ *Gas inlet holes*

I *Ignition port*

BELFAST ELECTRIC LIGHTING.

Plate 71.

Culverts and Street Boxes.

Fig. 15. *Sectional Plan.*

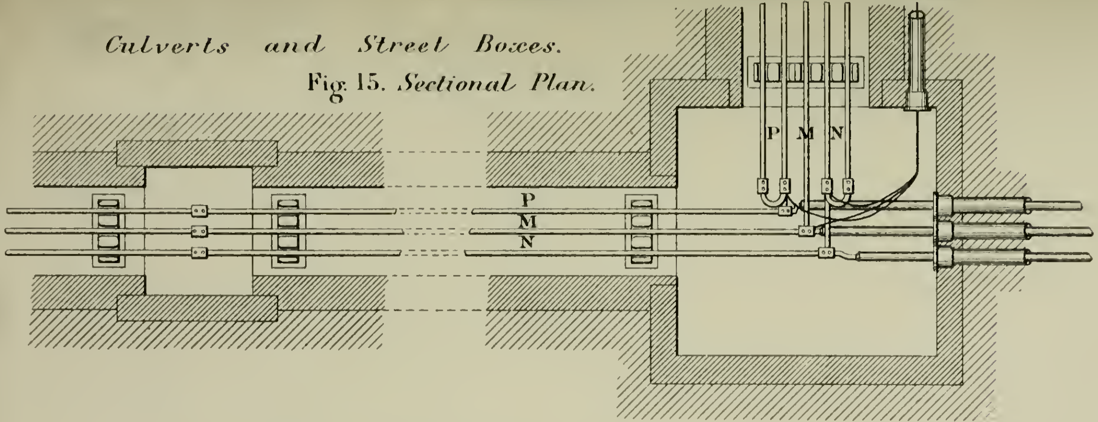


Fig. 17. *Transverse Section of three-way culvert.*

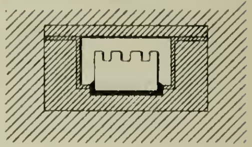


Fig. 16. *Sectional Elevation.*

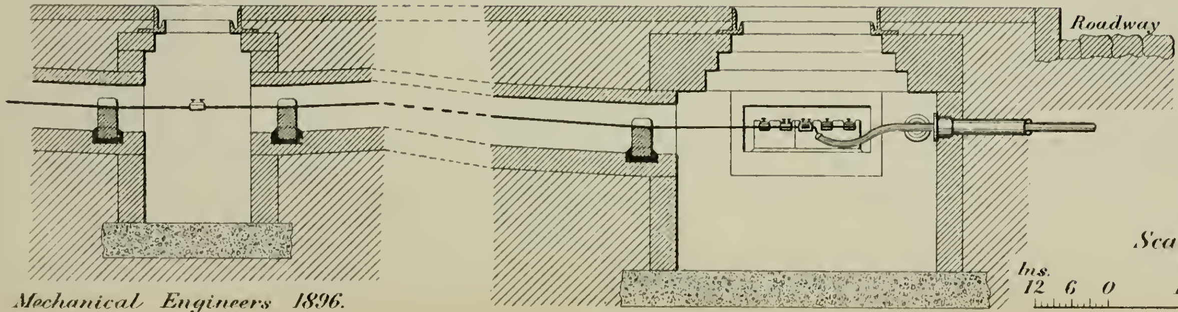
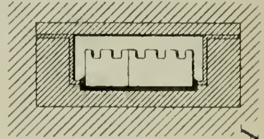


Fig. 18. *Transverse Section of five-way culvert.*



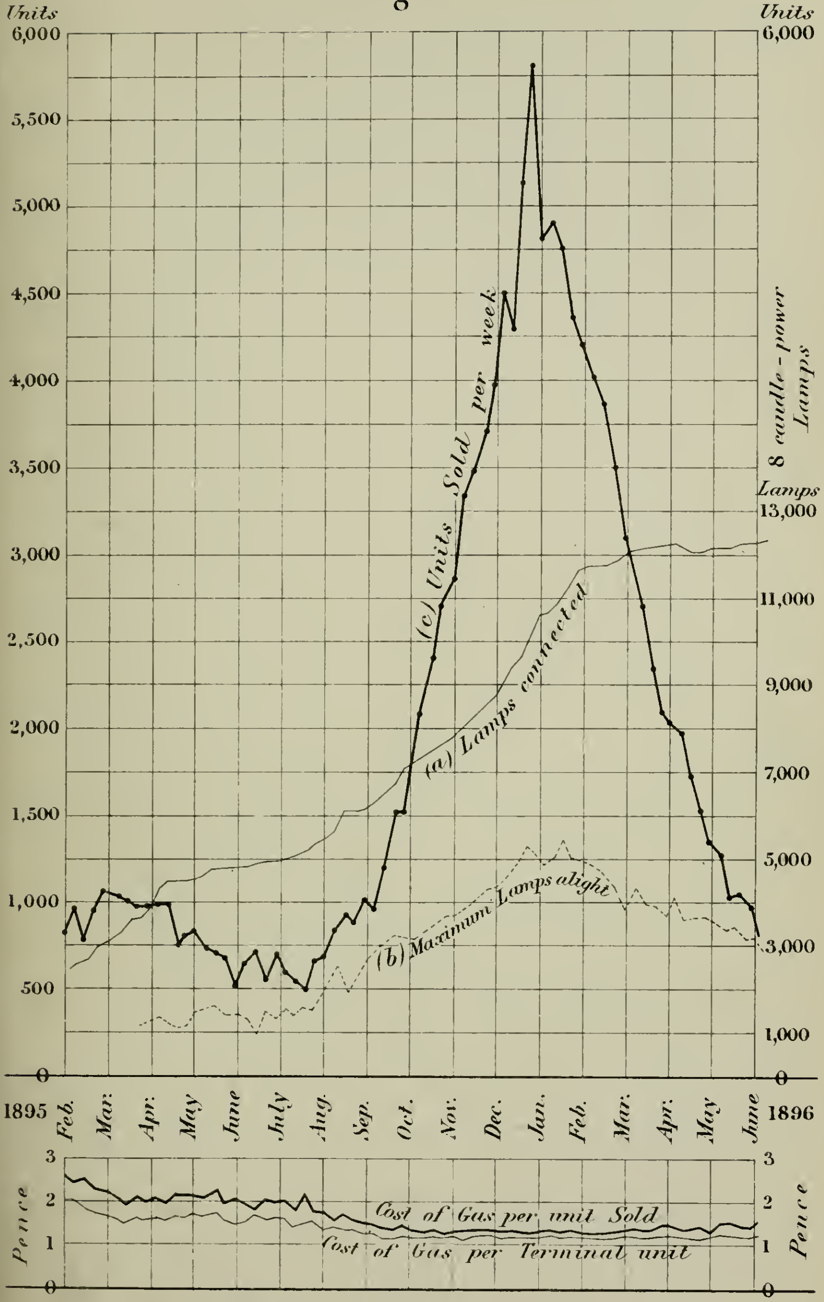
Scale $1/32^{nd}$

Ins. 12 6 0 1 2 3 Feet 4

Mechanical Engineers 1896.

Plate 71.

Fig: 19.


Units
6,000
5,500
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Units
6,000
8 candle-power Lamps
Lamps
13,000
11,000
9,000
7,000
5,000
3,000
1,000
0
(c) Units Sold per week
(a) Lamps connected
(b) Maximum Lamps alight
1895
Feb.
Mar.
Apr.
May
June
July
Aug.
Sep.
Oct.
Nov.
Dec.
Jan.
Feb.
Mar.
Apr.
May
June
1896
Pence
3
2
1
0
Cost of Gas per unit Sold
Cost of Gas per Terminal unit

BELFAST ELECTRIC LIGHTING.

Load Curves.

Fig. 20.

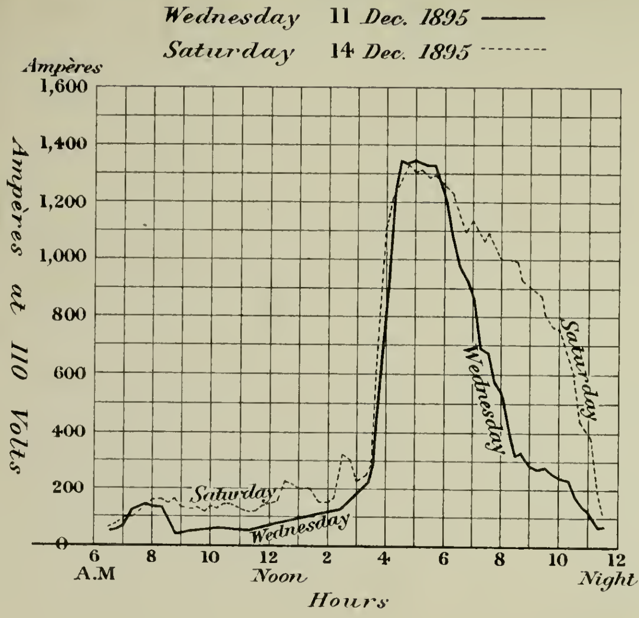


Fig. 21.

Midwinter and Midsummer.

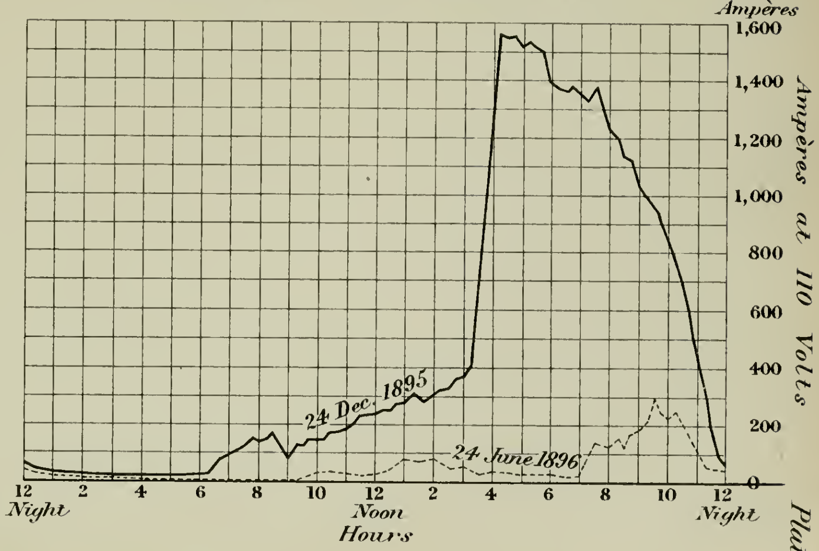
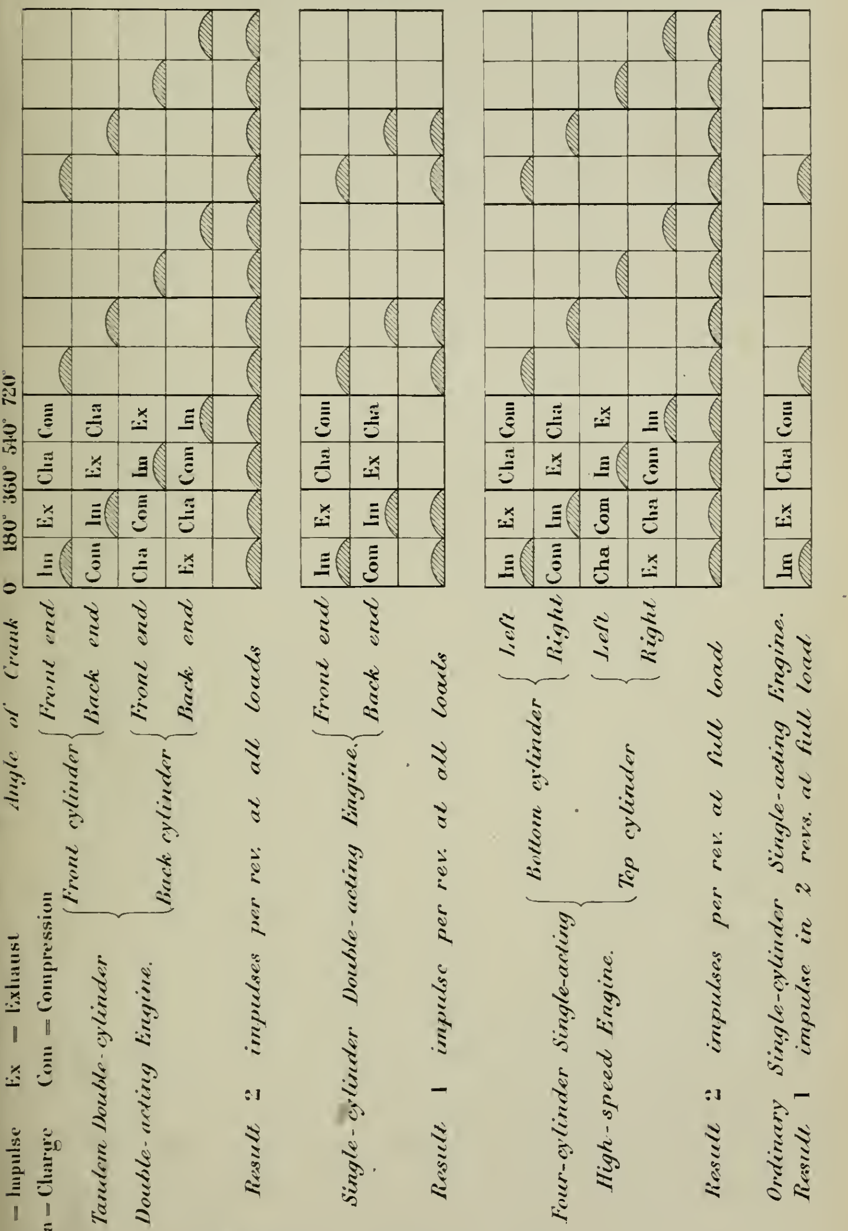


Fig. 22. *Diagram of relative positions of Operations in Cylinders, showing also number of Impulses in different Engines.*


Im = Impulse Ex = Exhaust
Cha = Charge Com = Compression
Angle of Crank 0 180° 360° 540° 720°
Tandem Double-cylinder Double-acting Engine.
Front cylinder
Front end Im Ex Cha Com
Back end Com Im Ex Cha
Back cylinder
Front end Cha Com Im Ex
Back end Ex Cha Com Im
Result 2 impulses per rev. at all loads
Single-cylinder Double-acting Engine.
Front end Im Ex Cha Com
Back end Com Im Ex Cha
Result 1 impulse per rev. at all loads
Four-cylinder Single-acting High-speed Engine.
Bottom cylinder
Left Im Ex Cha Com
Right Com Im Ex Cha
Top cylinder
Left Cha Com Im Ex
Right Ex Cha Com Im
Result 2 impulses per rev. at full load
Ordinary Single-cylinder Single-acting Engine.
Im Ex Cha Com
Result 1 impulse in 2 revs. at full load

Mechanical Engineers 1896.

BELFAST ELECTRIC LIGHTING. *Plate 75.*

Indicator Diagrams from
No. 6 Tandem Double-cylinder Double-acting Engine.
See Table 1.

Vertical Scale 180 lbs. per inch.

Front cylinder, front end.

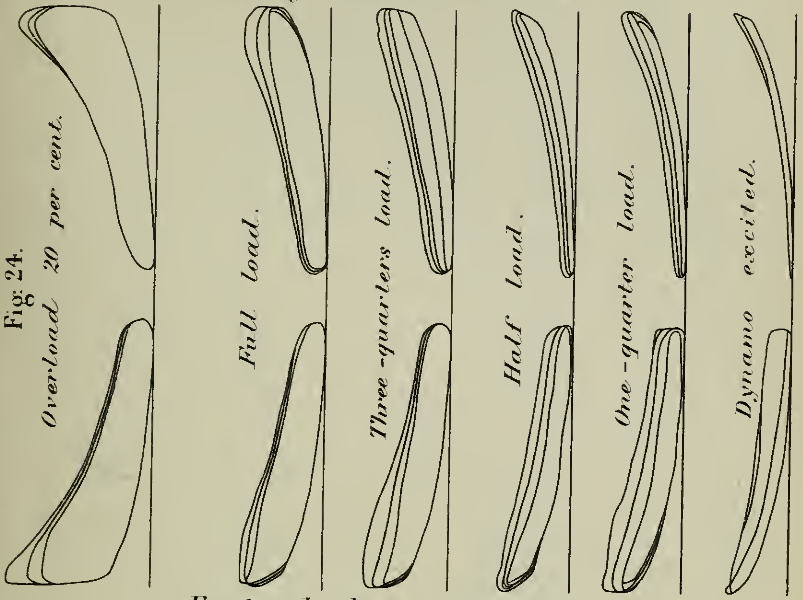


Fig. 24.

Front cylinder, back end.

Back cylinder, front end.

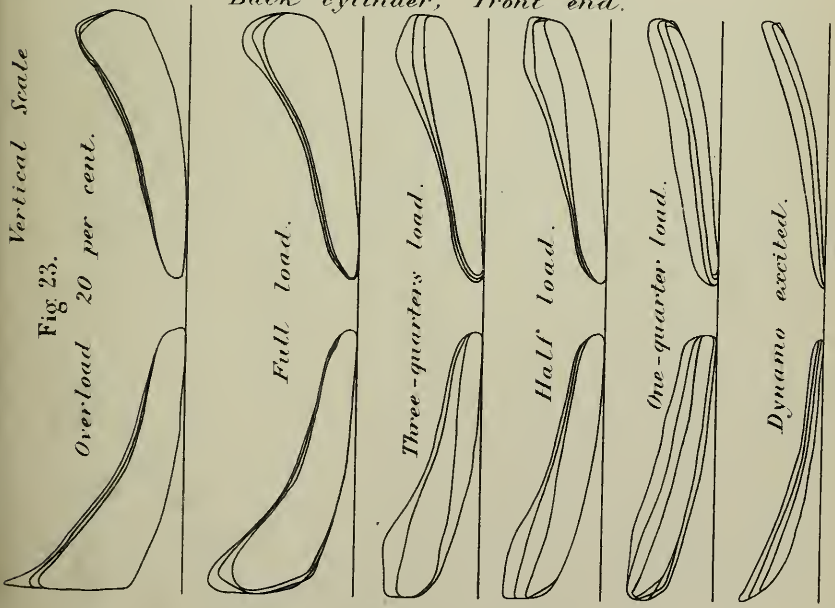


Fig. 23.

Back cylinder, back end.

BELFAST ELECTRIC LIGHTING. *Plate 76.*

Governing and Graduation of Explosions in Tandem Double-cylinder Double-acting Engines.

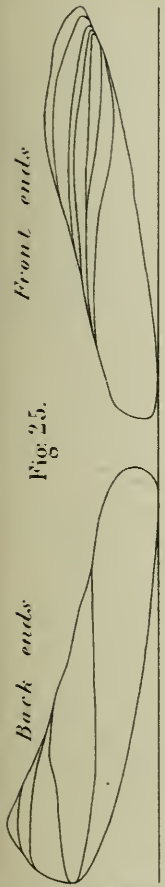


Fig. 25.

Light load before adjustment, showing late firing with high exhaust

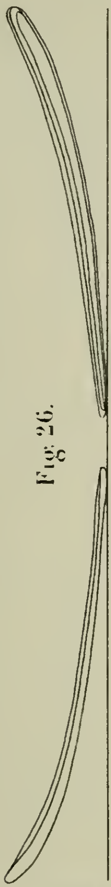


Fig. 26.

Light load after adjustment

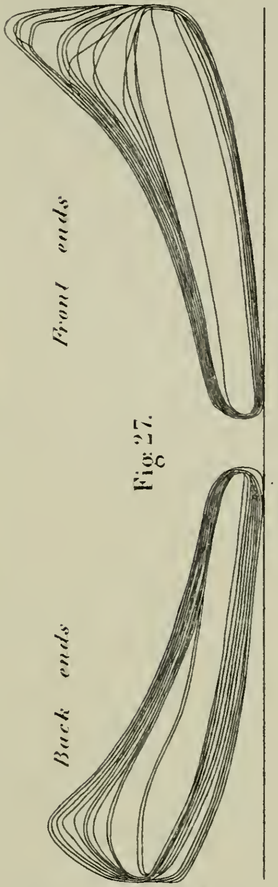


Fig. 27.

Graduated impulses

Vertical Scale 120 lbs. per inch (Figs. 25–27)

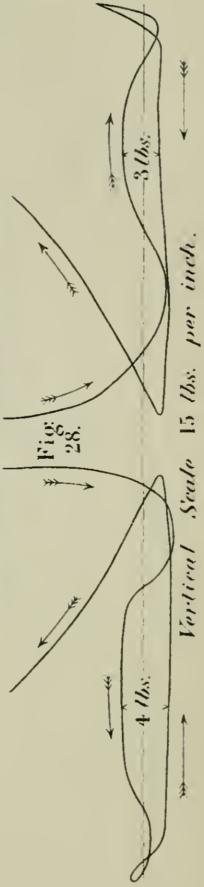
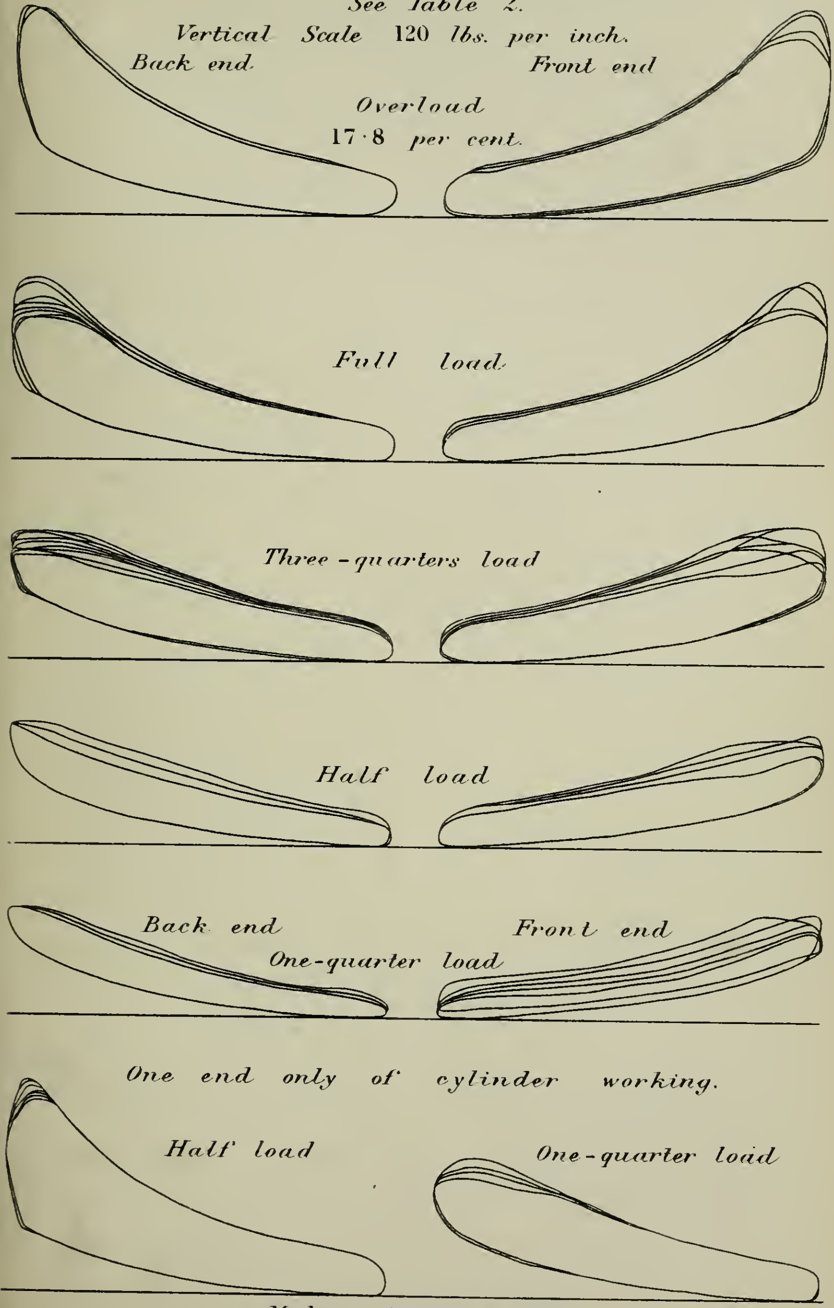


Fig. 28.

Exhaust and Charging strokes

Fig: 29. *Indicator Diagrams from*
No 2 Single-cylinder Double-acting Engine.
See Table 2.
Vertical Scale 120 *lbs. per inch.*



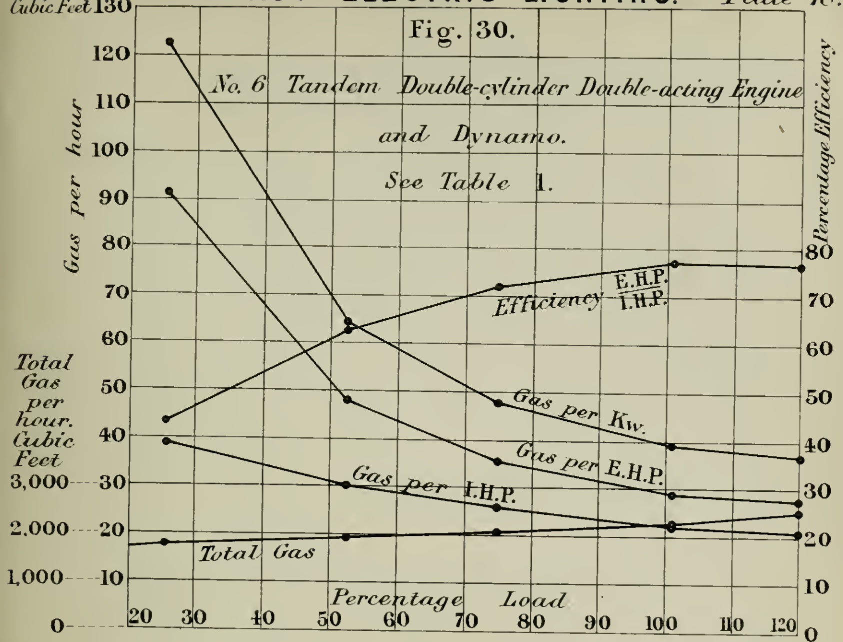


Fig. 30.

No. 6 Tandem Double-cylinder Double-acting Engine and Dynamo.

See Table 1.

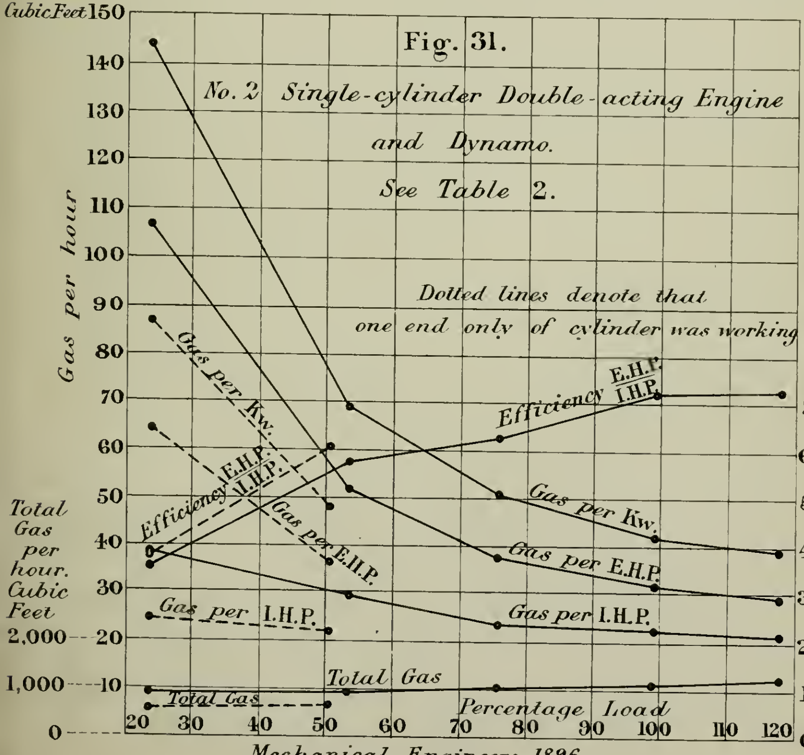


Fig. 31.

No. 2 Single-cylinder Double-acting Engine and Dynamo.

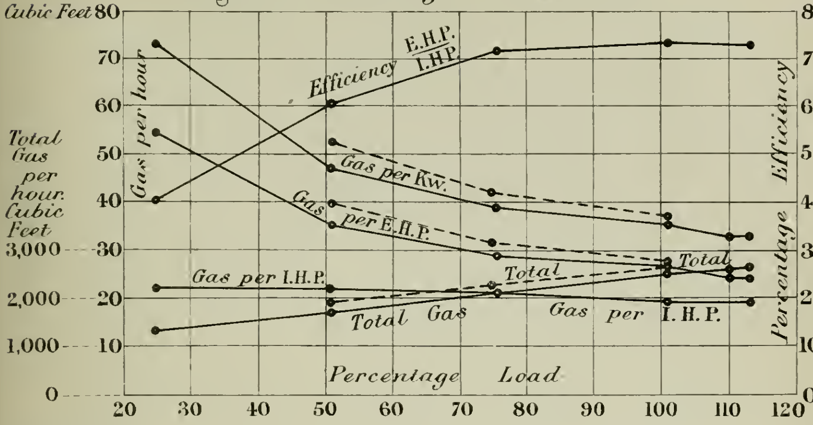
See Table 2.

Dotted lines denote that one end only of cylinder was working

BELFAST ELECTRIC LIGHTING. *Plate 79.*

Four-cylinder Single-acting High-speed Vertical Engine, coupled direct to Dynamo.

Fig. 32. *No. 7 Engine. See Table 3.*



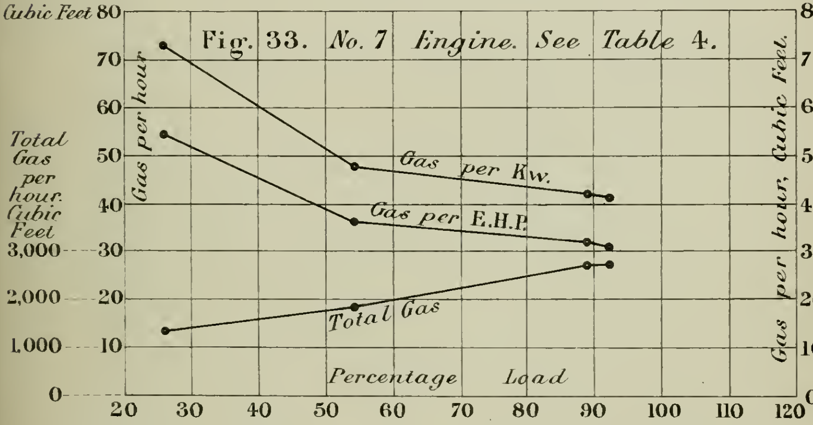


Fig. 33. *No. 7 Engine. See Table 4.*

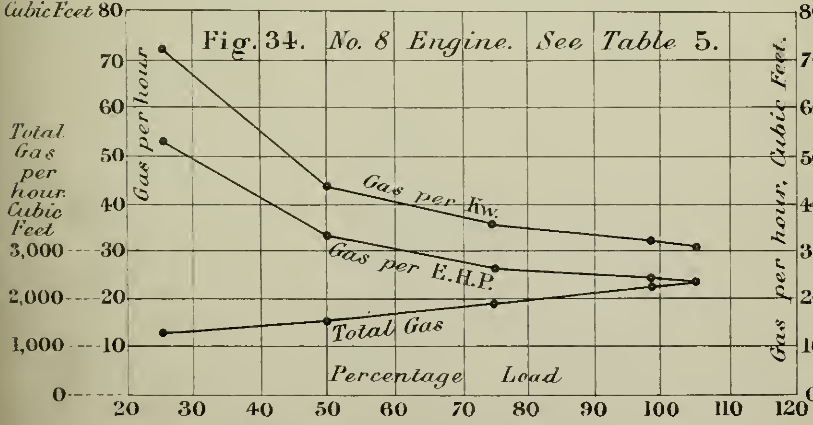


Fig. 34. *No. 8 Engine. See Table 5.*

Fig. 1.

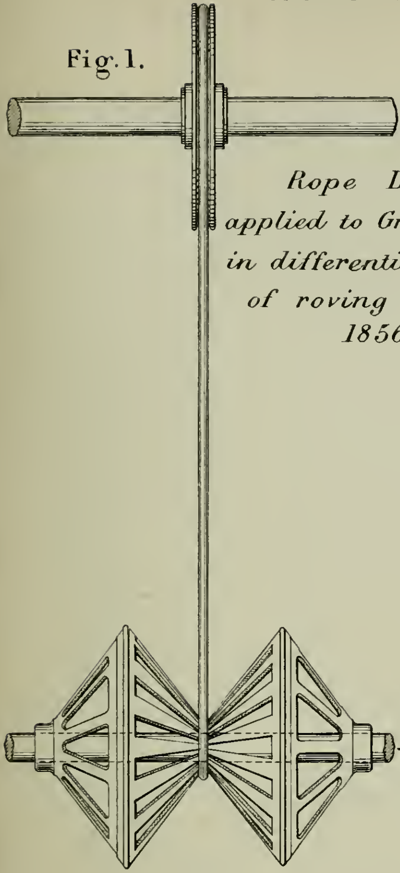
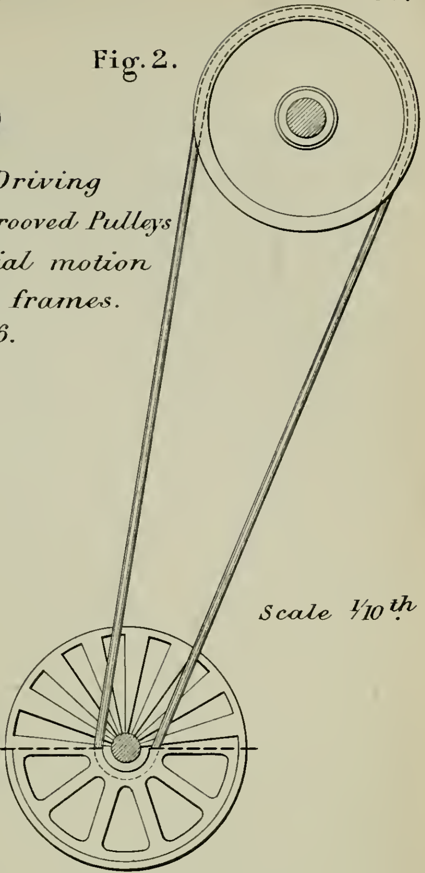


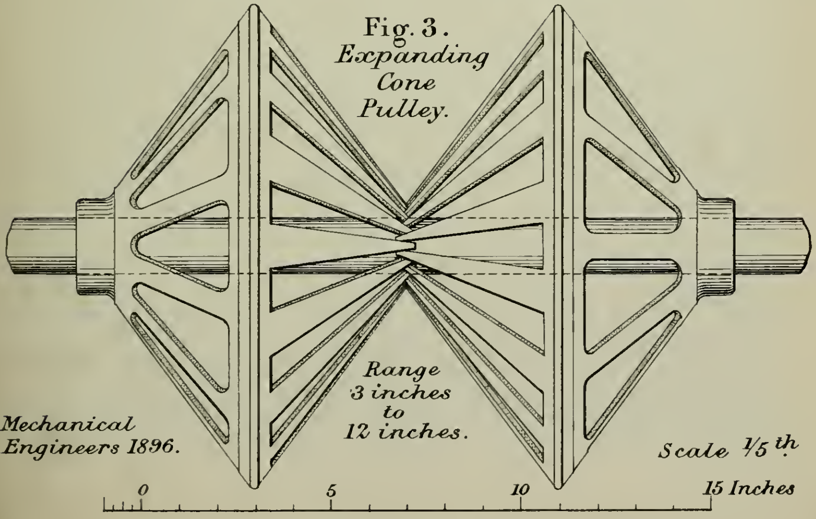
Fig. 2.



Rope Driving applied to Grooved Pulleys in differential motion of roving frames. 1856.

Scale 1/10th.

Fig. 3. *Expanding Cone Pulley.*

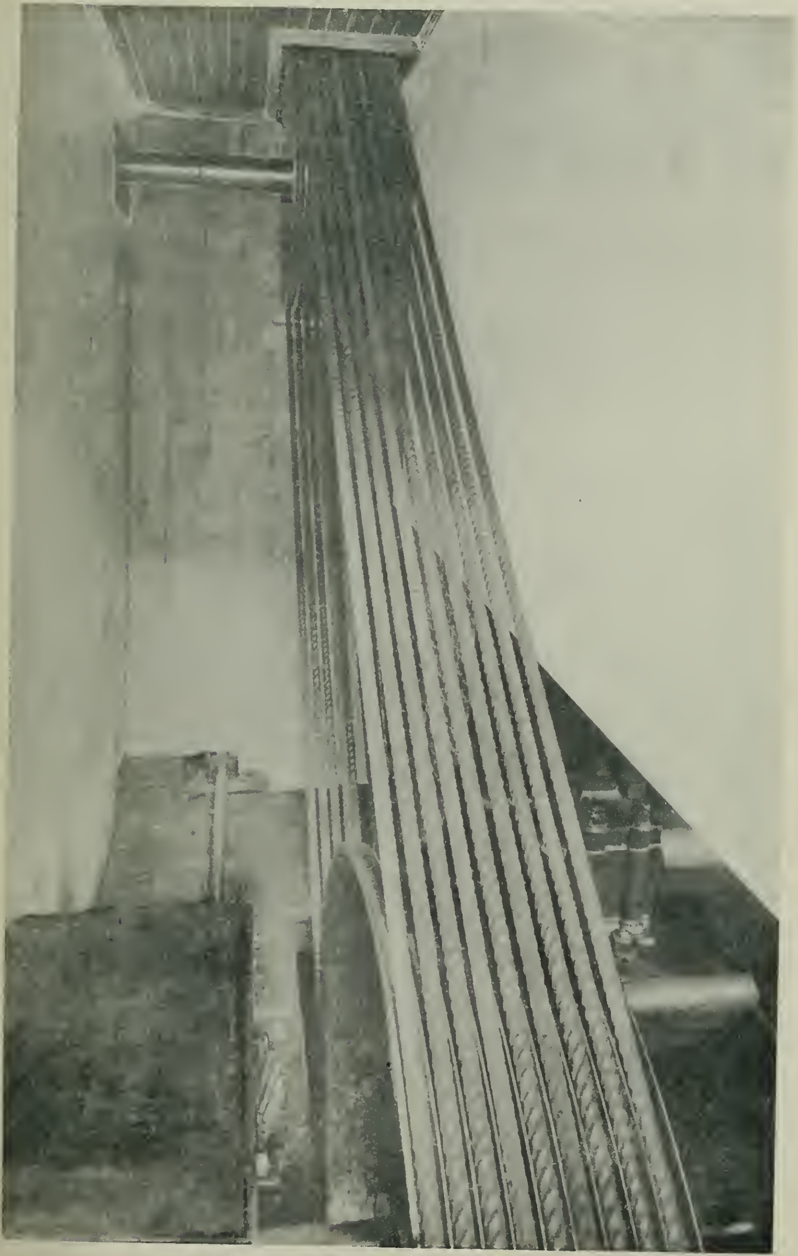


Range 3 inches to 12 inches.

Mechanical Engineers 1896.

Scale 1/5th.

Fig. 4. *First Main Driving by Ropes. Erected in* 1863, *and still running in the Falls Foundry, Belfast. Over* 200 *H.P.*



ROPE DRIVING.

Main Rope Drive from Flywheel, Owen O'Cork Mills, Belfast. Erected in 1873.

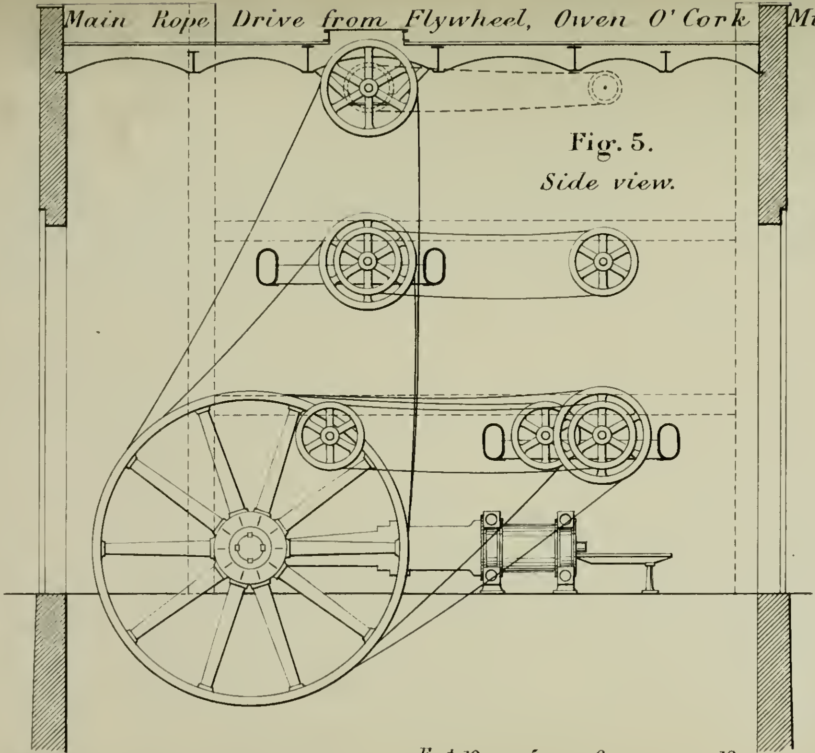


Fig. 5.
Side view.

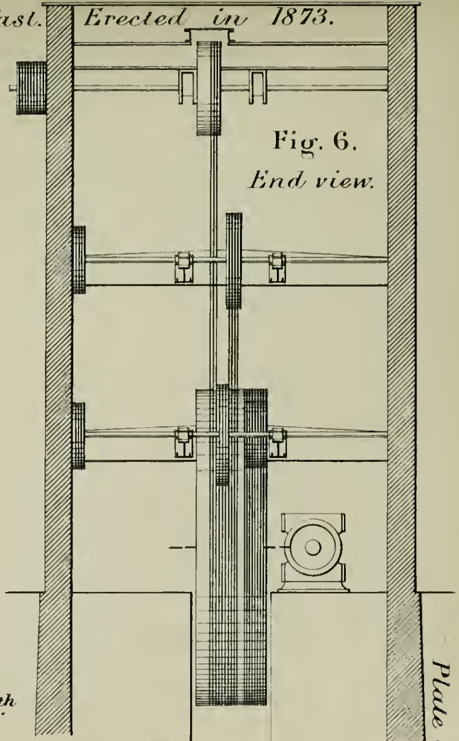


Fig. 6.
End view.

Scale 1/180th.

Plate 82.

ROPE DRIVING.

Fig. 7. *Rope Driving applied to shafts inclined at any angle up to 3°. 1875.*

Scale 1/24th.

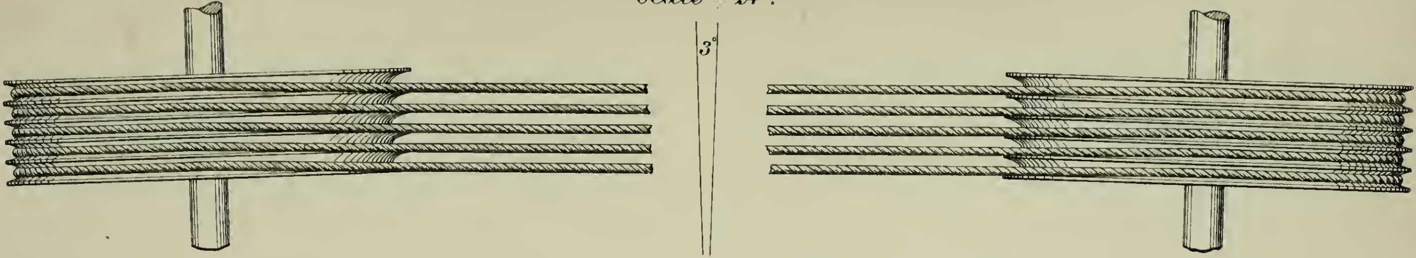
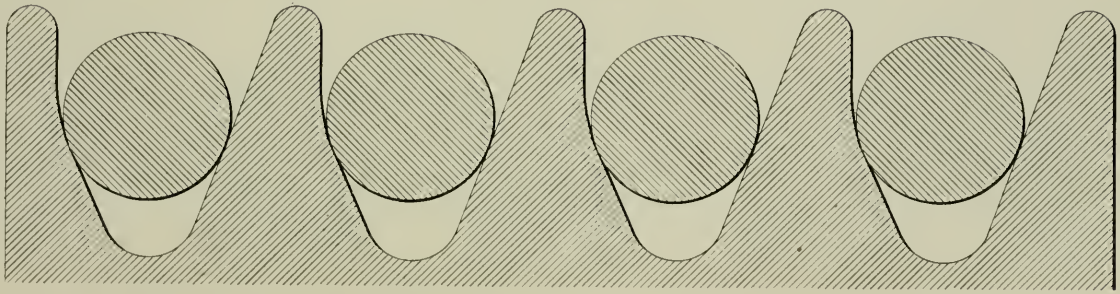


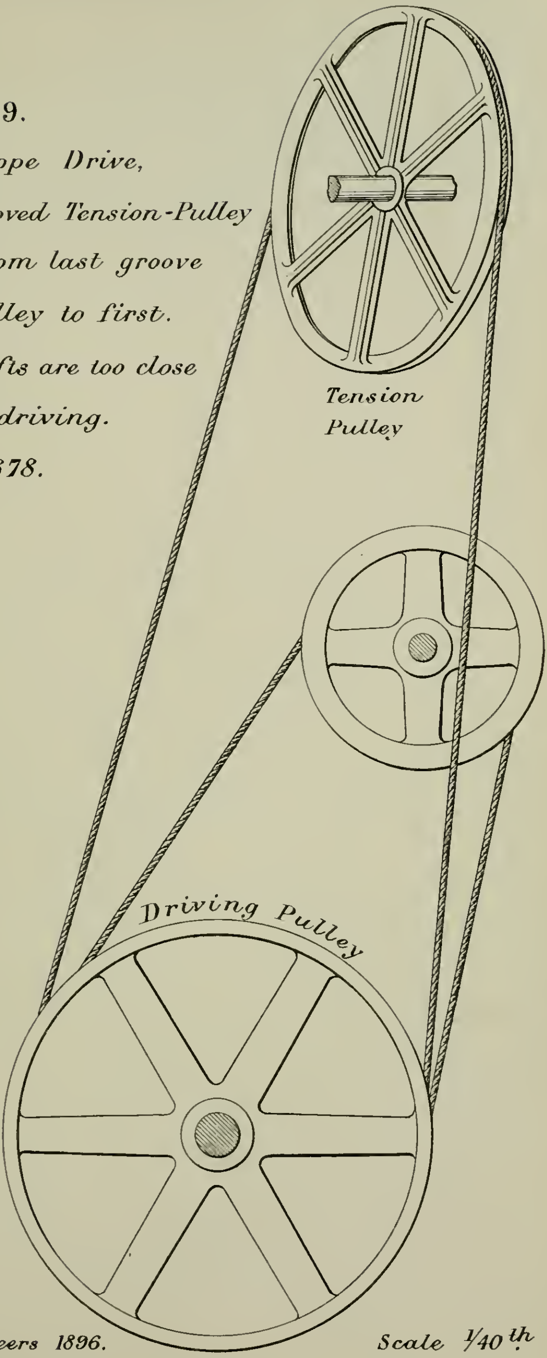
Fig. 8. *Section of Grooves used when shafts are at an angle above 3°. 1875.*



Scale half size.

Fig. 9.

Endless Rope Drive, with single-grooved Tension-Pulley leading rope from last groove of driving pulley to first. Used when shafts are too close for ordinary driving. Introduced 1878.



Scale 1/40th.

ROPE DRIVING.

Fly-wheel specially designed for Rope Driving. 1879.

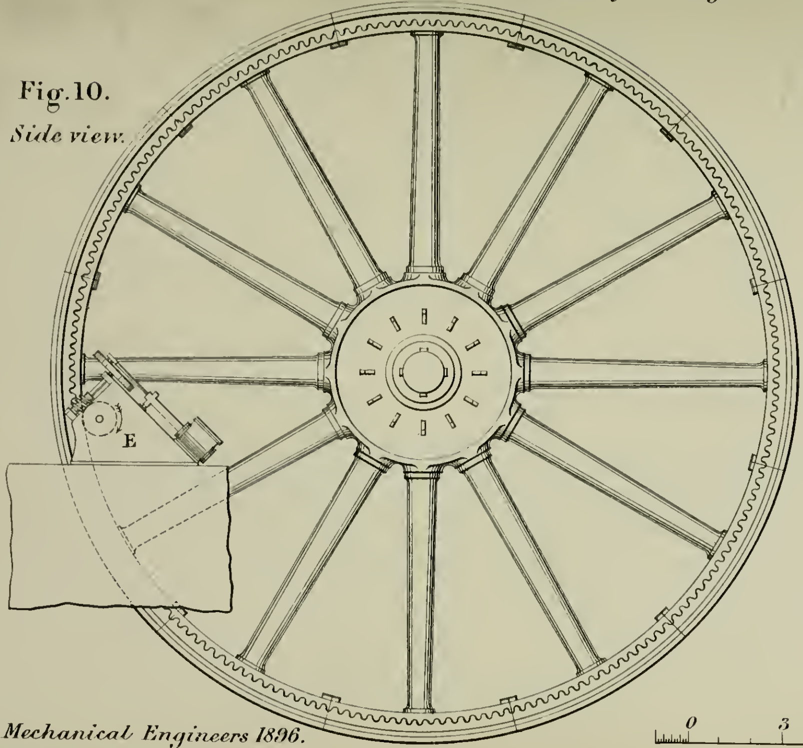


Fig. 10.

Side view.

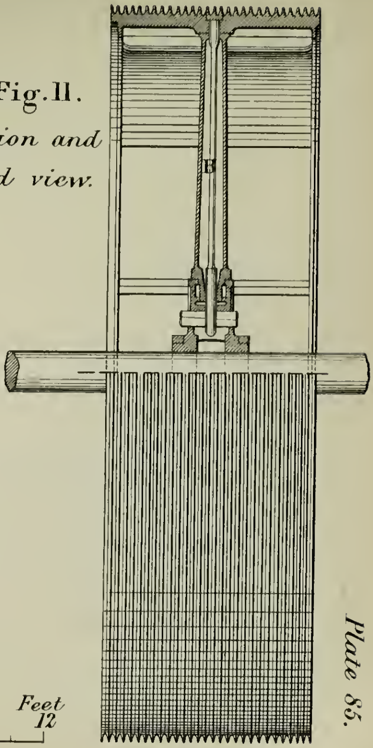


Fig. 11.

Section and End view.

Scale 1/72nd.

ROPE DRIVING.

Fly-wheel specially designed for Rope Driving. 1879.

Fig.12. *Side view of Rim.*

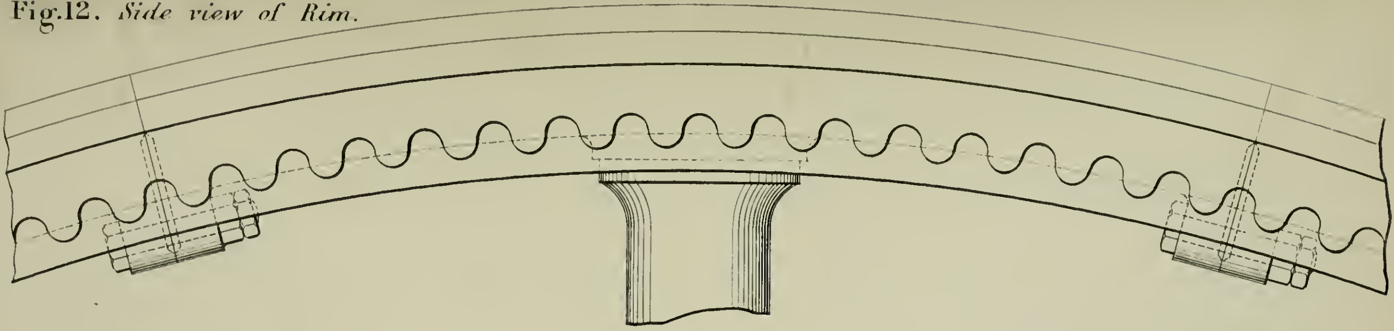
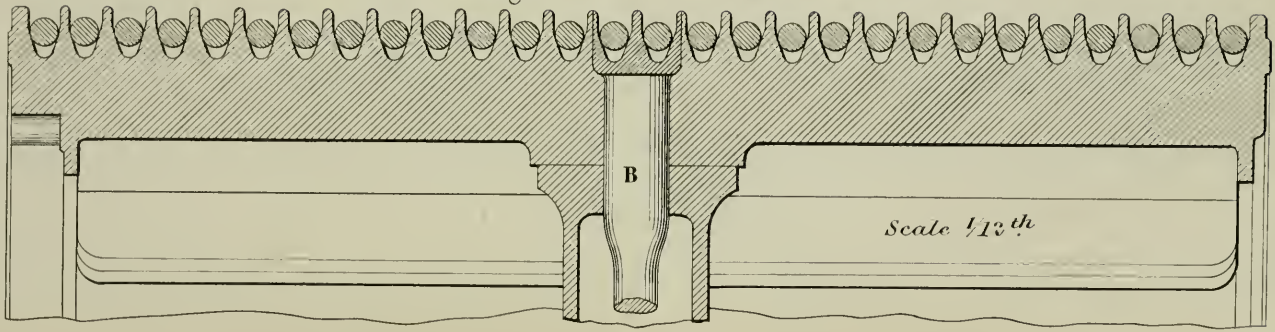


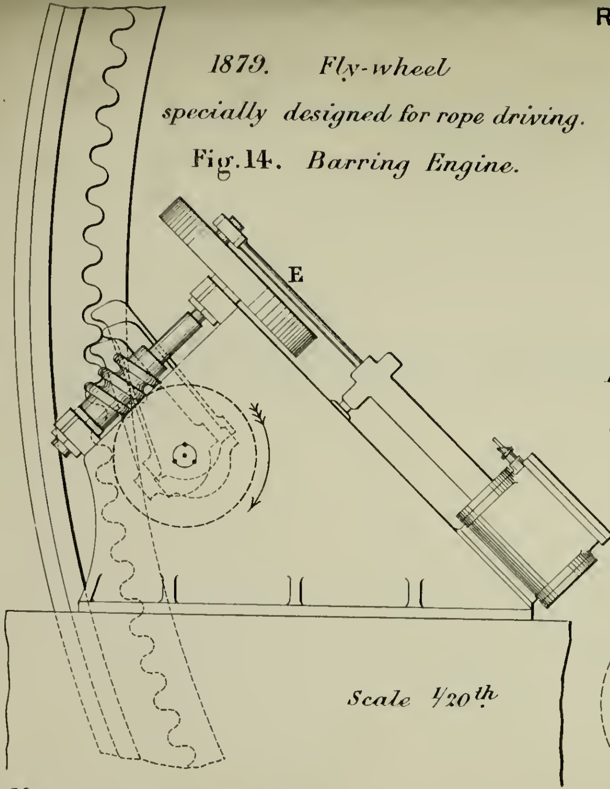
Fig.13. *Section of Rim.*



Scale 1/12th.

ROPE DRIVING.

1879. Fly-wheel
specially designed for rope driving.
Fig. 14. Barring Engine.



Scale 1/20th.

Fig. 15.
Main Rope Drive
600 I.H.P.
Hilden Flax Mills,
Lisburn.
Erected in 1864,
and still running.

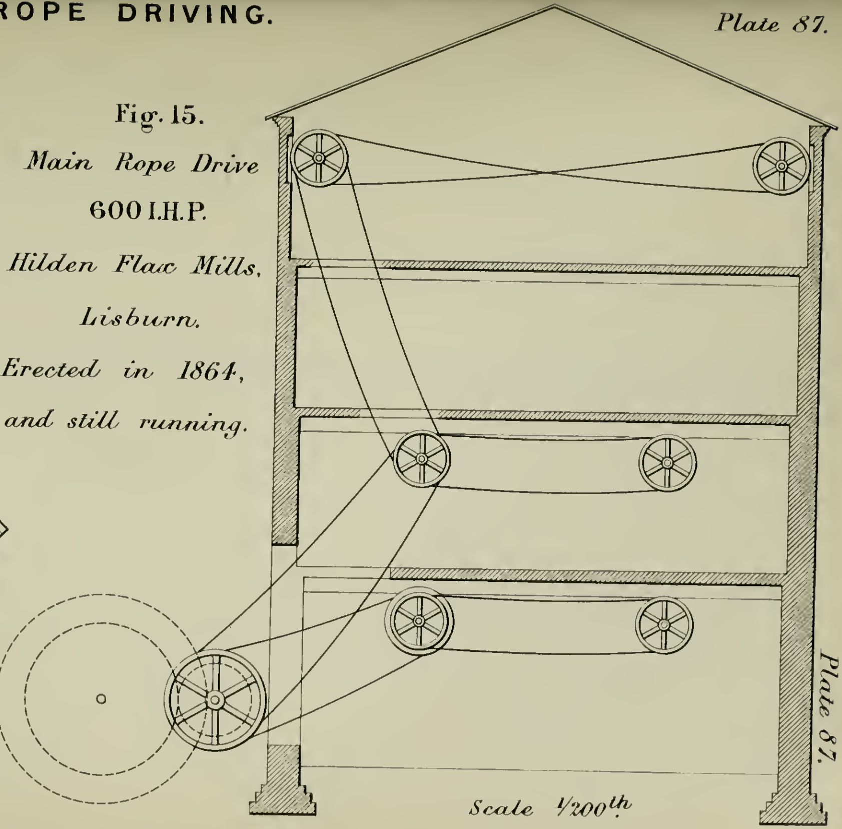


Plate 87.

Scale 1/200th.

Mechanical Engineers 1896.

ROPE DRIVING.

Crossed Rope Drive. 1879.

Fig. 16. Elevation.

Scale 1/48th.

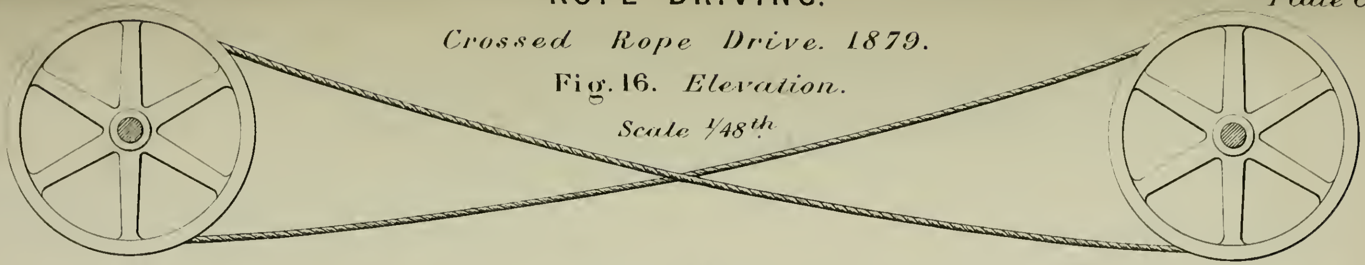


Fig. 17. Plan.

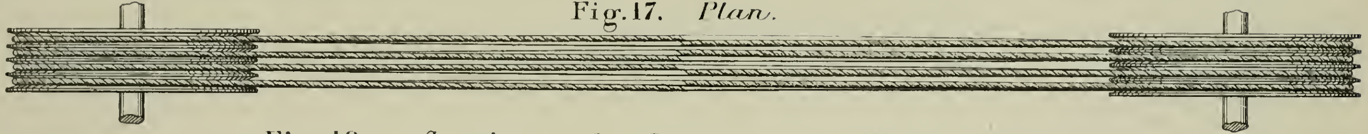


Fig. 18. Section of Grooves. Scale half size.

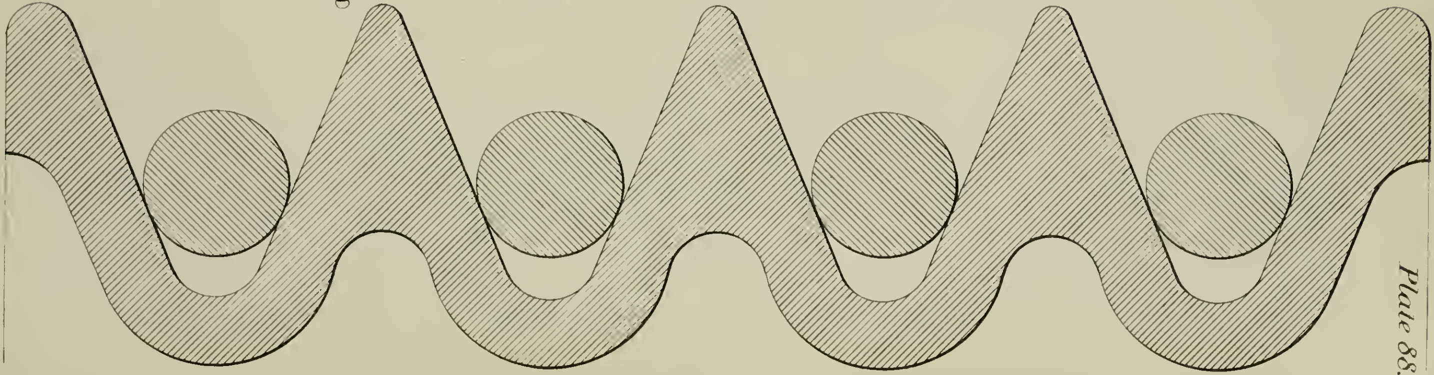


Plate 88.

ROPE DRIVING.

Half - Crossed Rope Drive.

Separate Rope to each Groove. 1879.

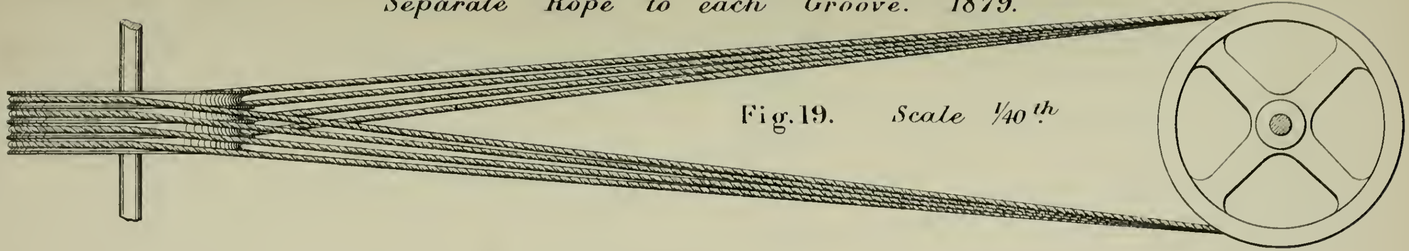
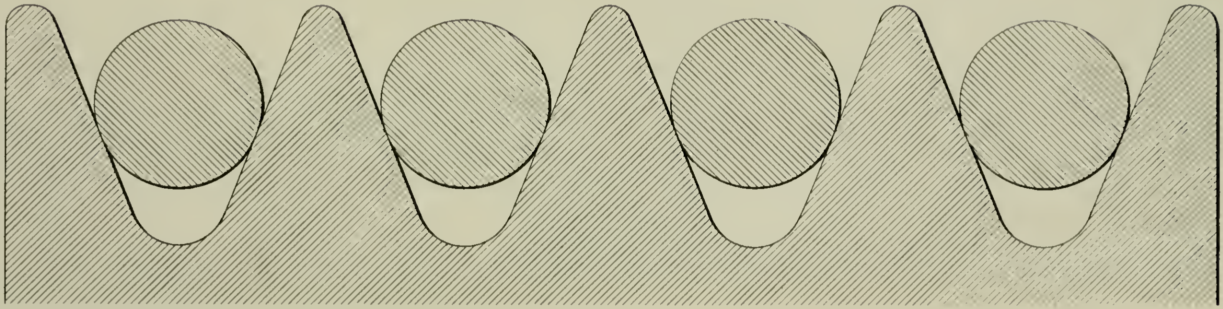


Fig. 19. *Scale $\frac{1}{40}$th.*

Fig. 20. *Section of Grooves. Scale half size.*



ROPE DRIVING.

Fig. 21.

Rope-Drive with shafts at right angles.

1879.

Scale 1/36th.

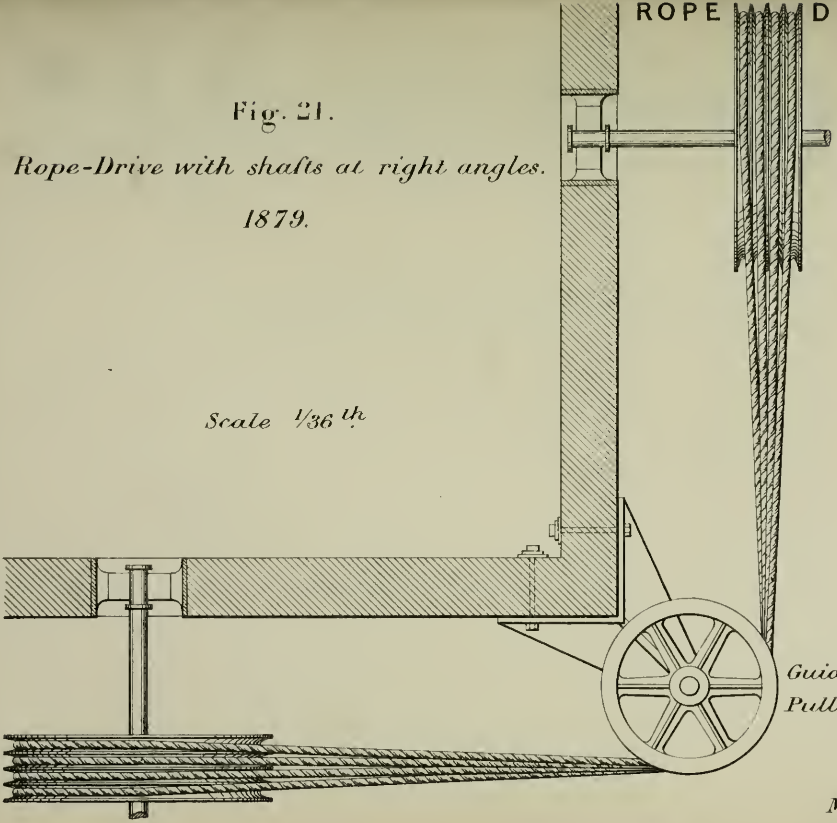
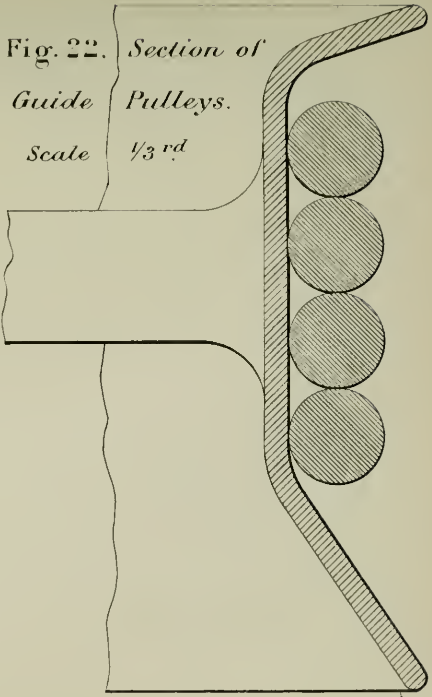


Fig. 22. Section of Guide Pulleys.

Scale 1/3rd.



Pl. 90.

Mechanical Engineers 1896.

ROPE DRIVING.

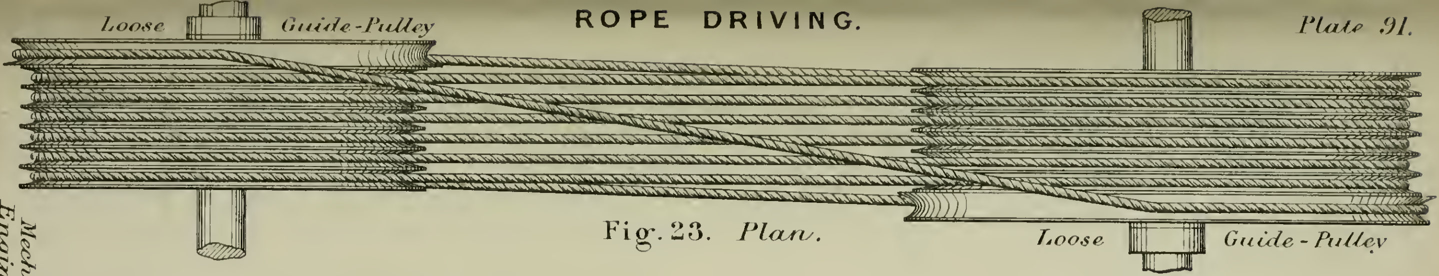


Fig. 23. Plan.

Endless Rope Drive,
with Loose Guide-Pulleys.
1889.

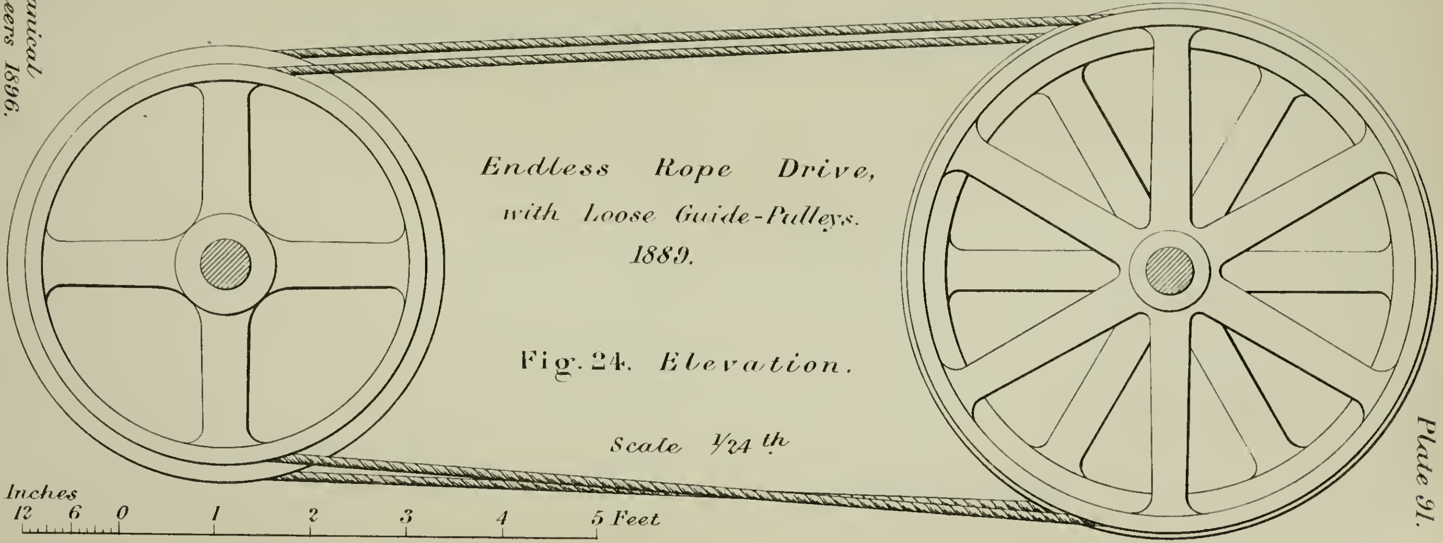
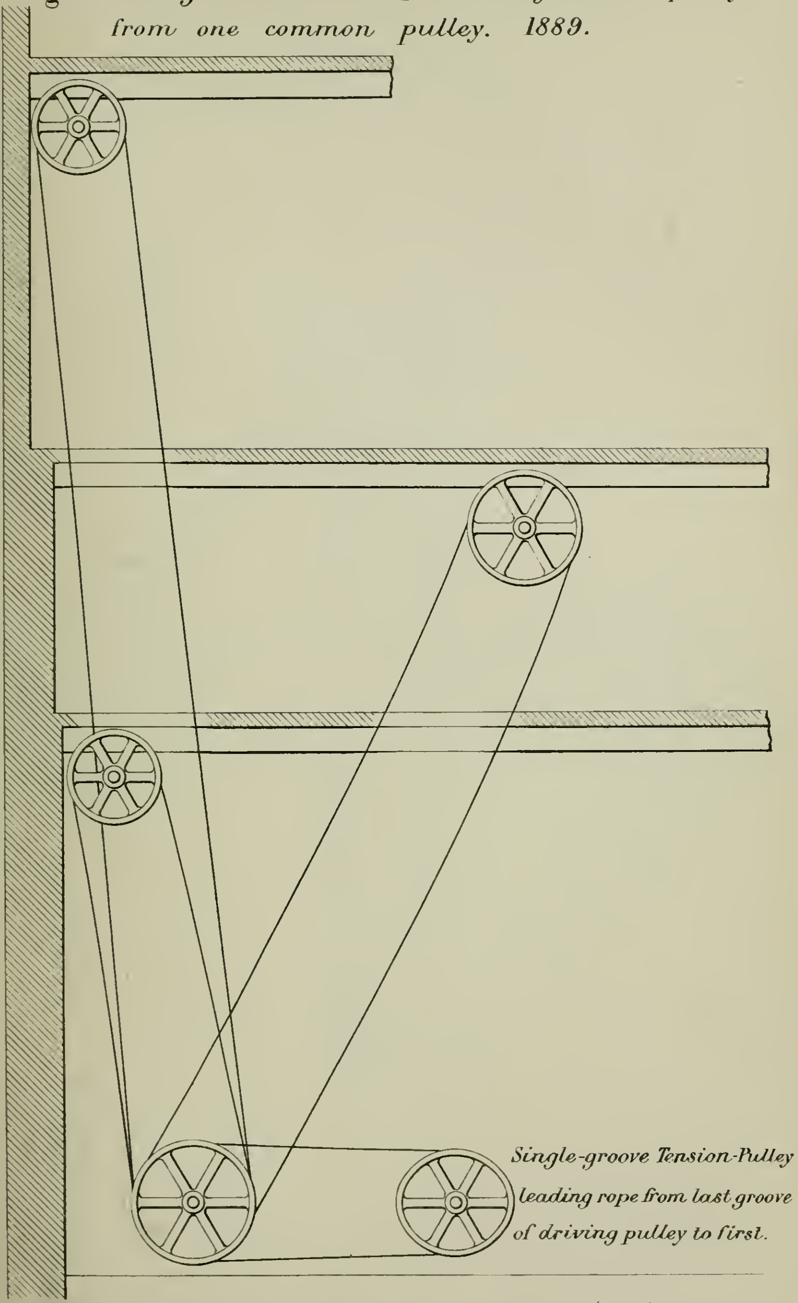


Fig. 24. Elevation.

Scale 1/24th.

Plate 91.

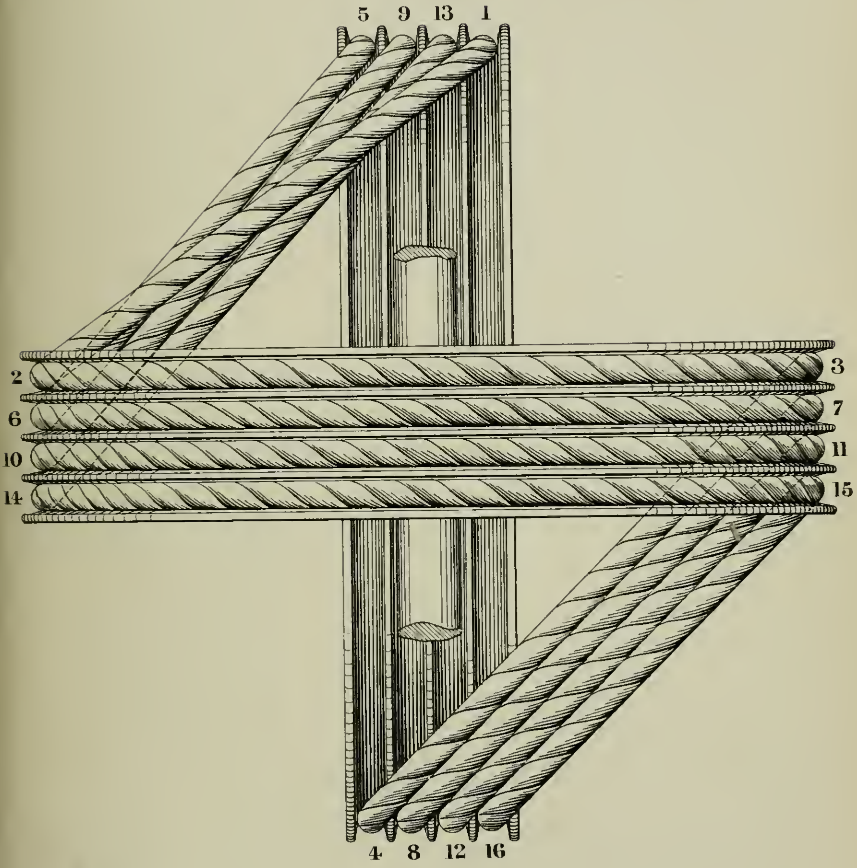
Fig. 25. *Single Endless Rope, driving several pulleys from one common pulley. 1889.*


Single-groove Tension-Pulley leading rope from last groove of driving pulley to first.

Mechanical Engineers 1896. *Scale 1/100th*

Endless Rope applied to Half-Cross Drive. 1890.

Fig. 26.



Mechanical Engineers 1896. *Scale 1/12th.*

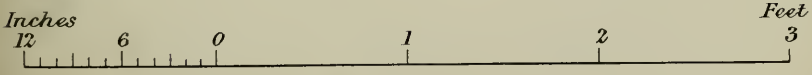
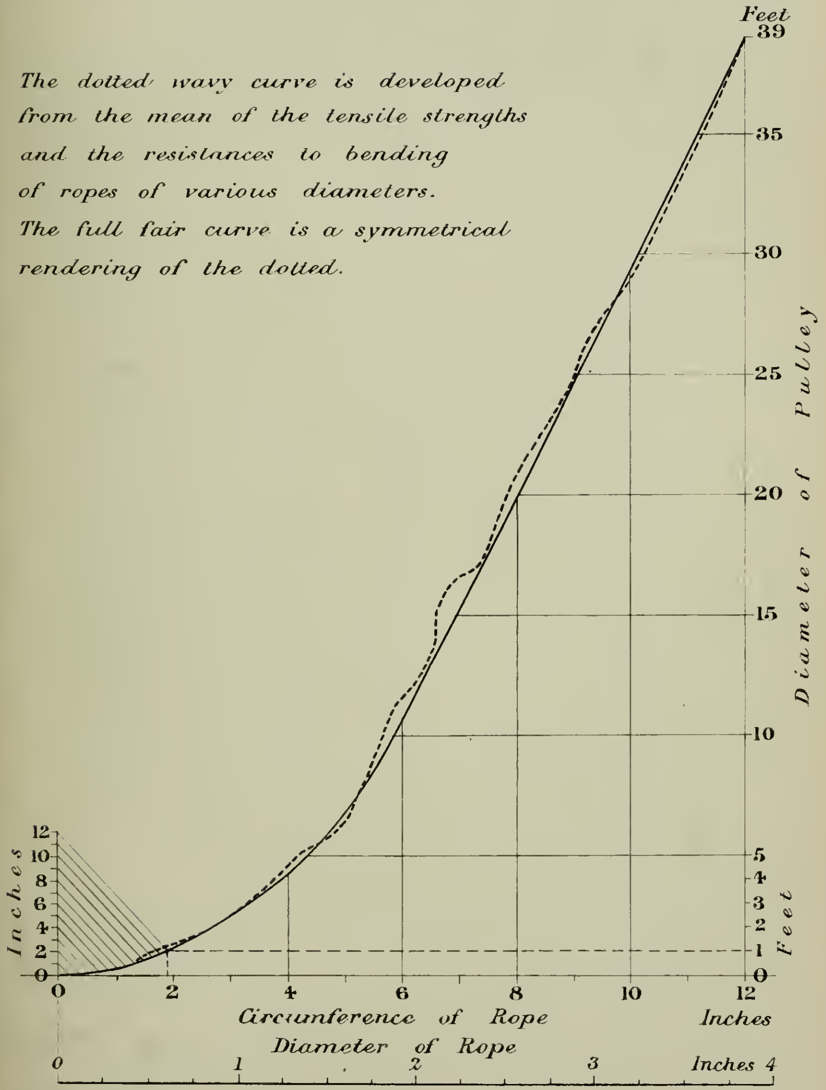


Fig. 27.

Theoretical Relation of Diameters of Ropes and Pulleys.



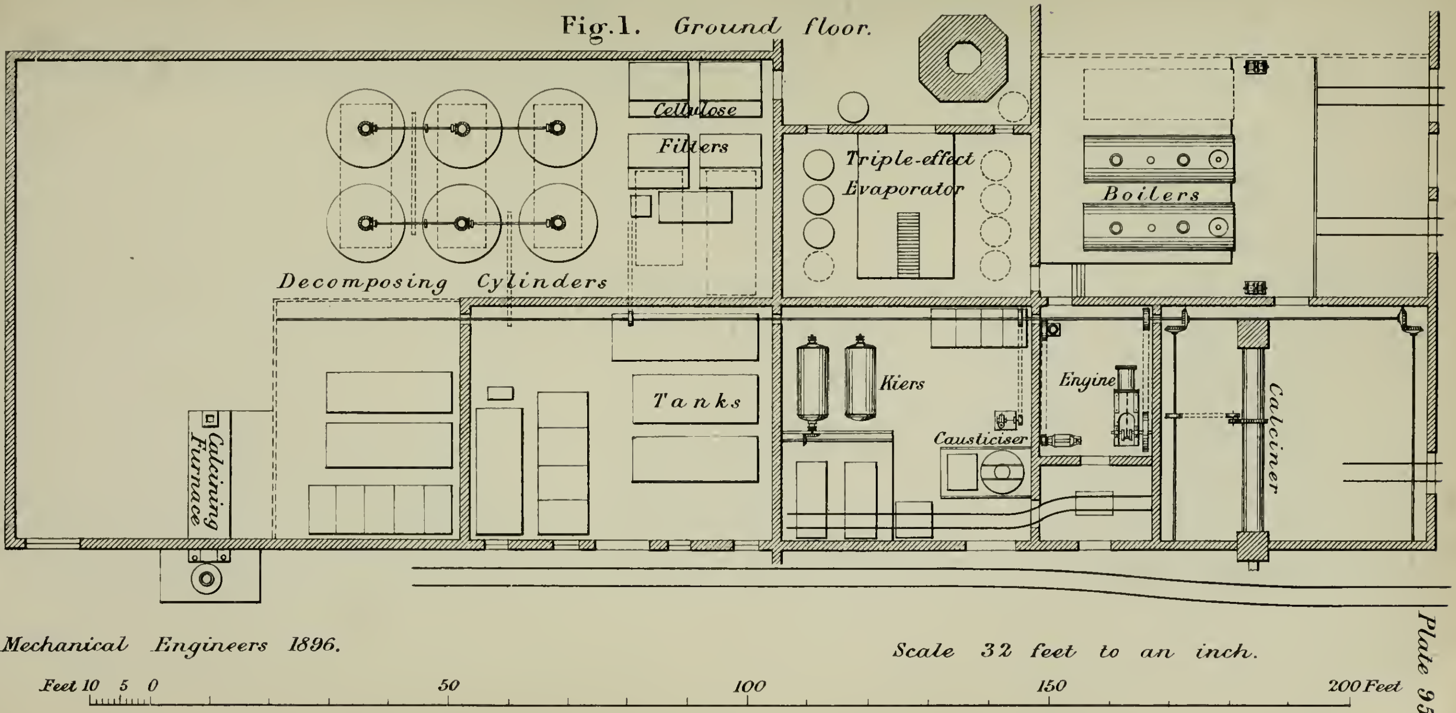
The dotted wavy curve is developed from the mean of the tensile strengths and the resistances to bending of ropes of various diameters.

The full fair curve is a symmetrical rendering of the dotted.

ALUMINA FACTORY.

Plan of Works at Larne Harbour.

Fig. 1. Ground floor.



Scale 32 feet to an inch.

Mechanical Engineers 1896.

ALUMINA FACTORY.

Plan of Works at Larne Harbour.

Fig. 2. First floor.

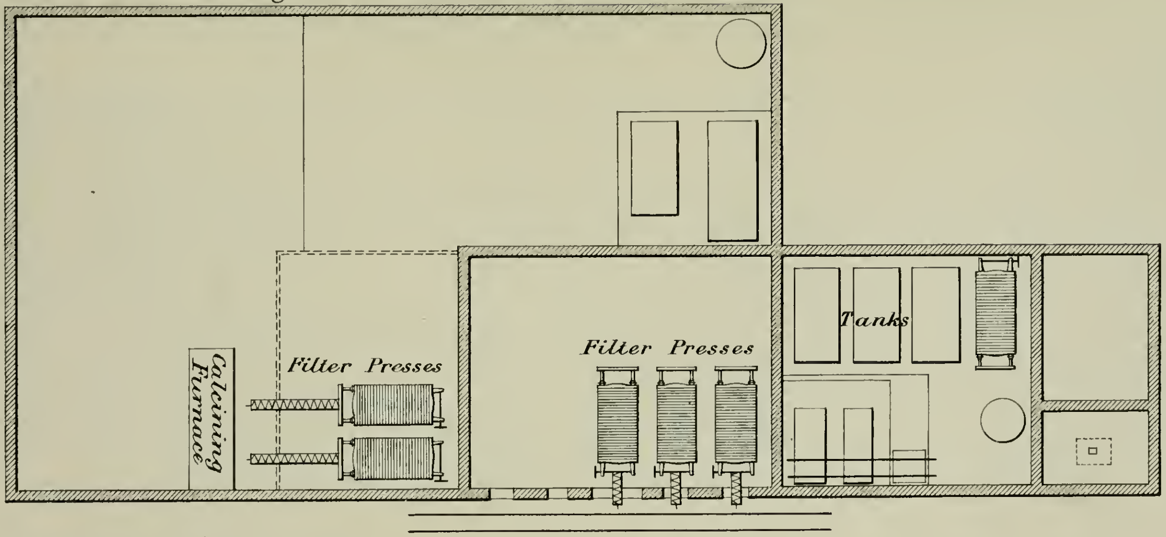
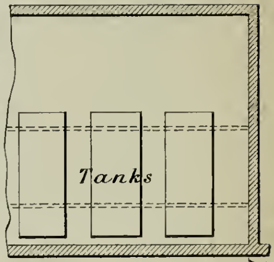


Fig. 3.

Second floor.



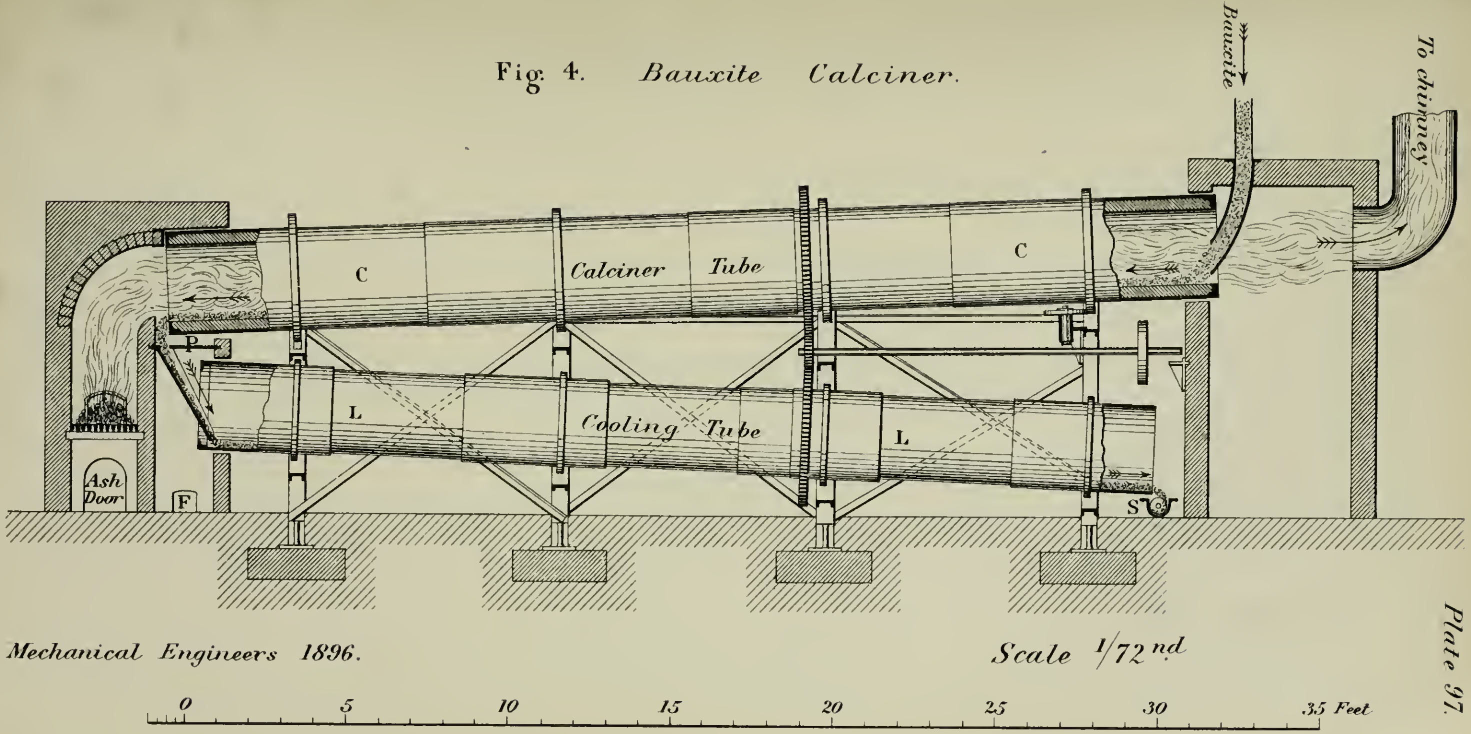
Mechanical Engineers 1896.

Scale 32 feet to an inch.

Feet 10 5 0 50 100 150 200 Feet

ALUMINA FACTORY.

Fig. 4. *Bauxite Calciner.*



Mechanical Engineers 1896.

Scale $^1/_{72}$nd.

ALUMINA FACTORY.

Pressure Kier.

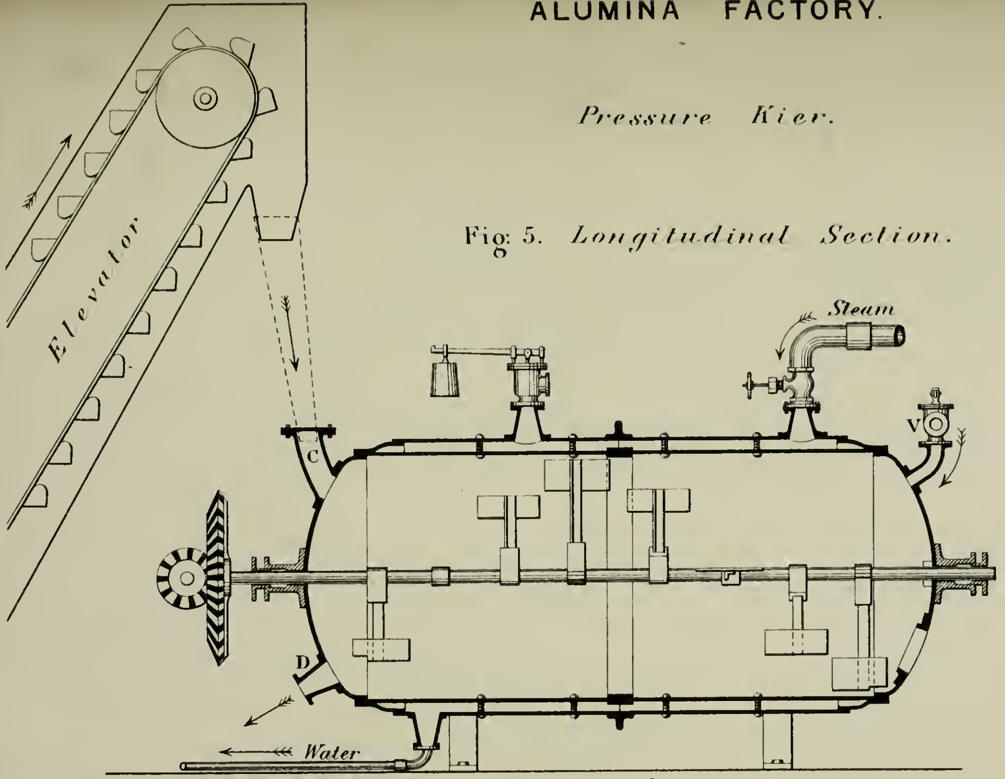


Fig: 5. Longitudinal Section.

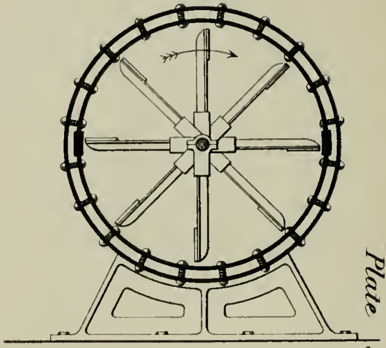


Fig: 6. Transverse Section.

Scale 1/48th

Ins. 12 6 0 3 6 9 12 Feet

Mechanical Engineers 1896.

BELFAST GAS WORKS.

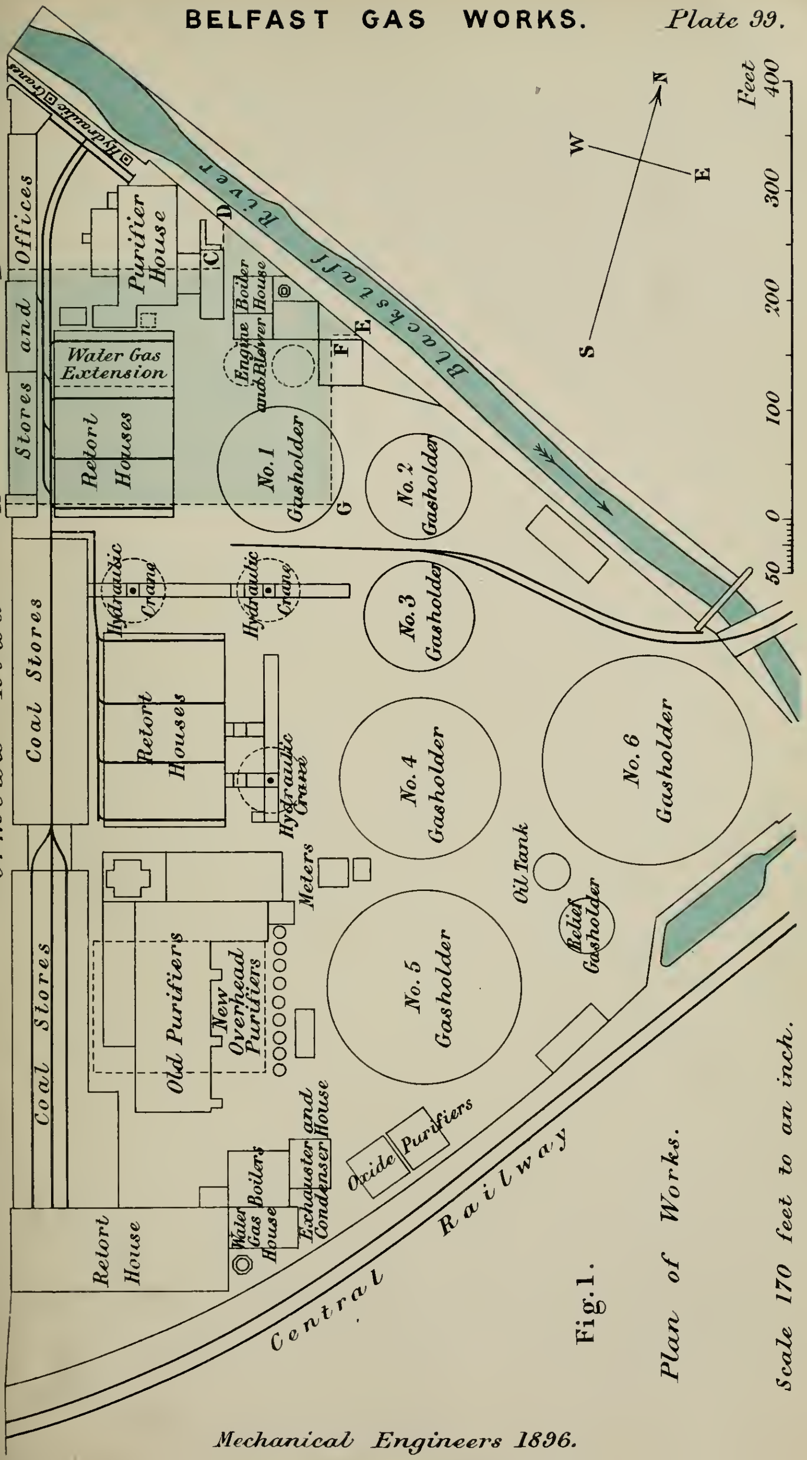


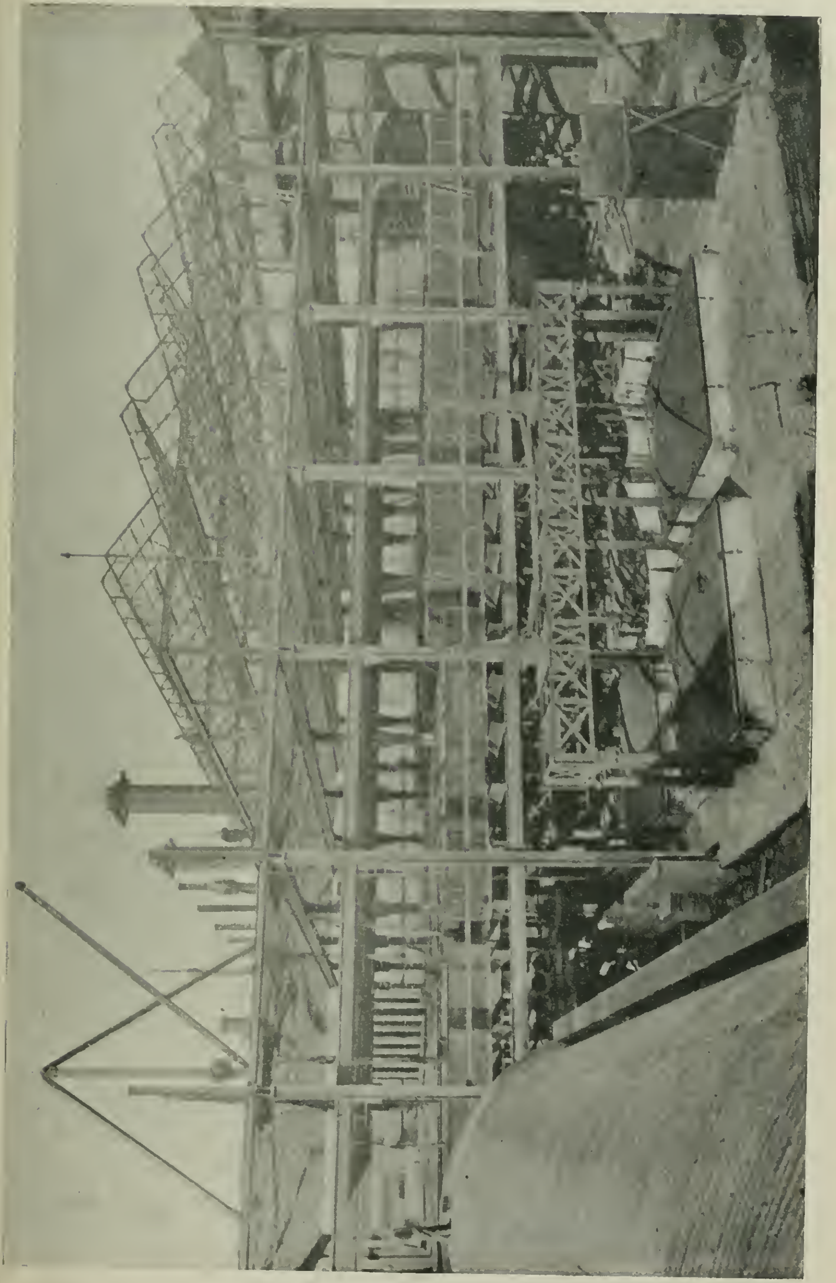
Fig. 1.

Plan of Works.

Scale 170 feet to an inch.

BELFAST GAS WORKS.

Fig. 2. *Overhead Purifiers.*



BELFAST GAS WORKS.

Crossing Box.

Fig. 3. Plan.

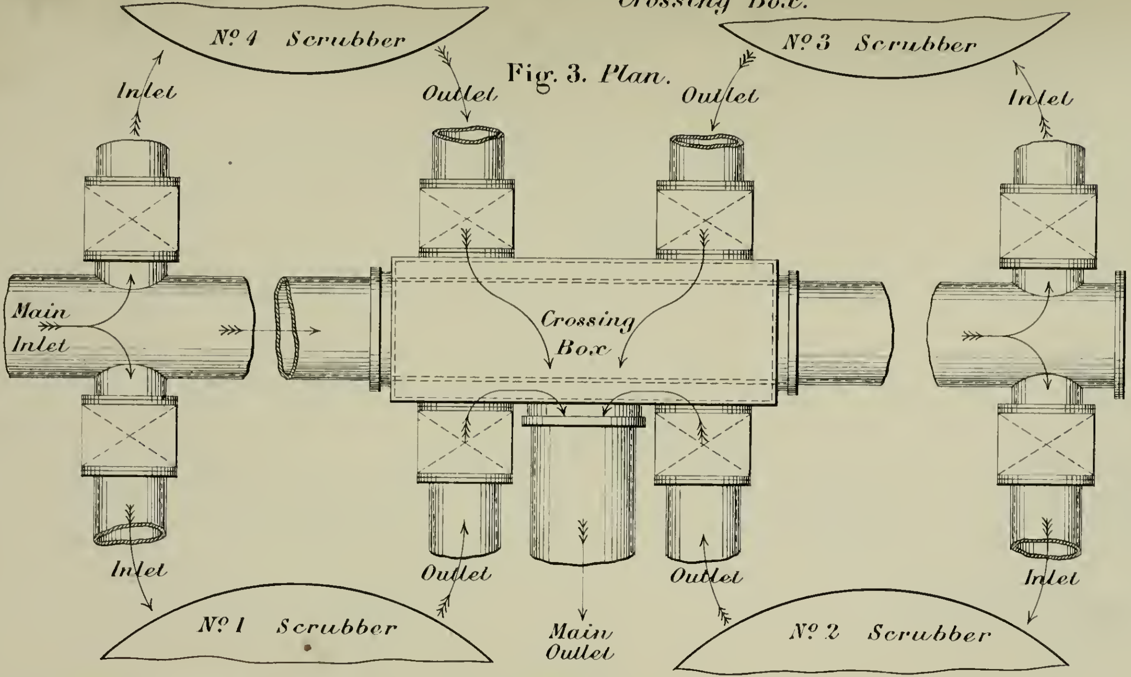
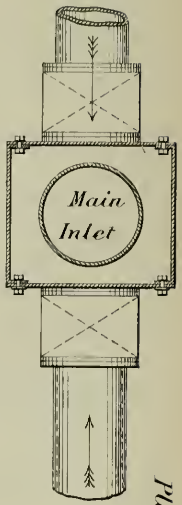


Fig. 4. Transverse Section.



Scale 1/48th.

Mechanical Engineers 1896.

Plate 101.

BELFAST GAS WORKS.

Crossing Box in Halves.

Fig. 5.

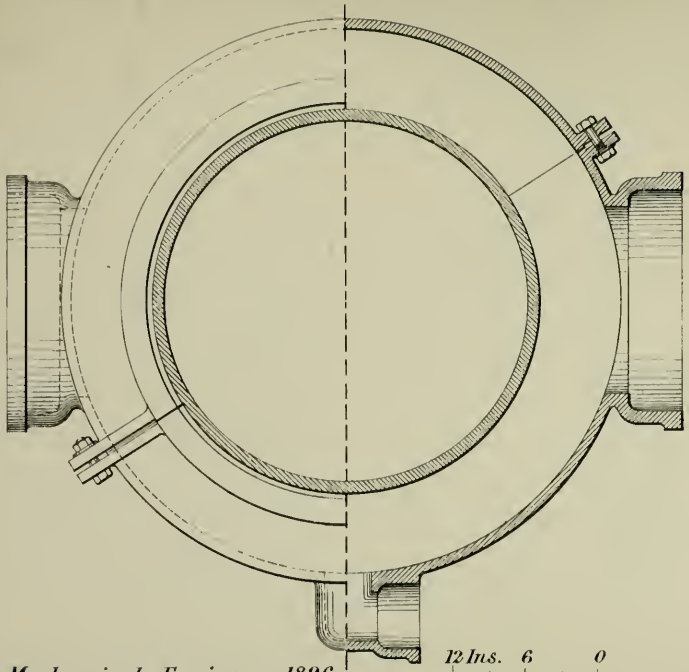
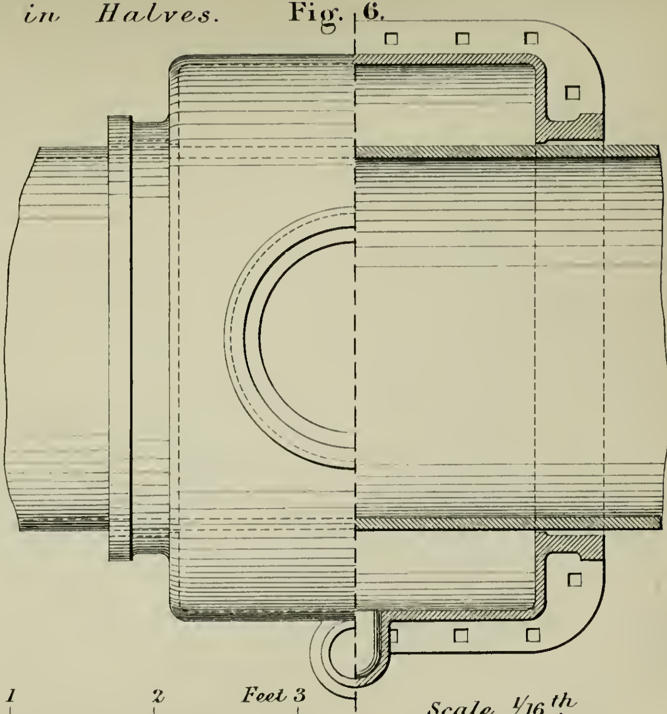


Fig. 6.



12 Ins. 6 0 1 2 Feet 3

Scale 1/16th.

Mechanical Engineers 1896.

BELFAST GAS WORKS.

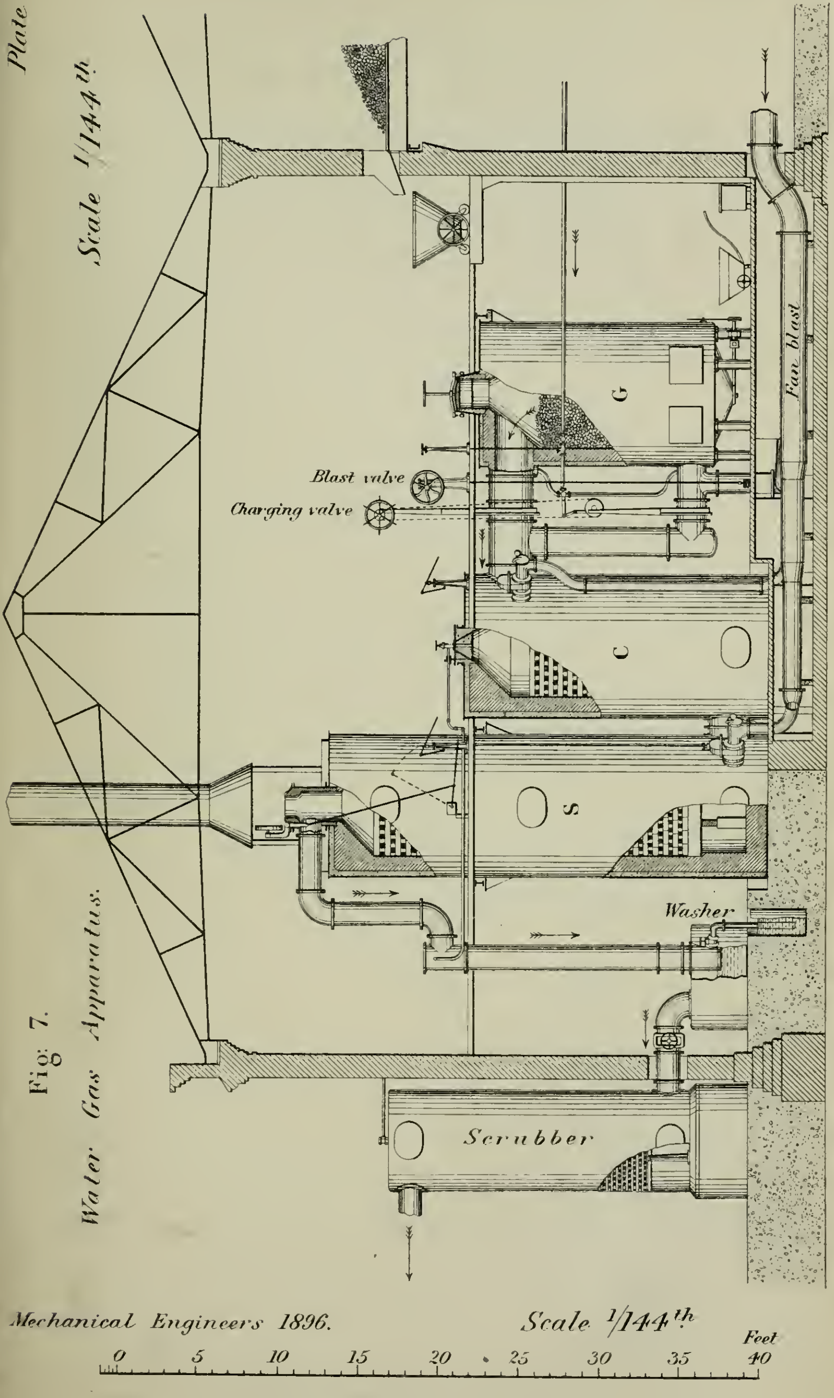


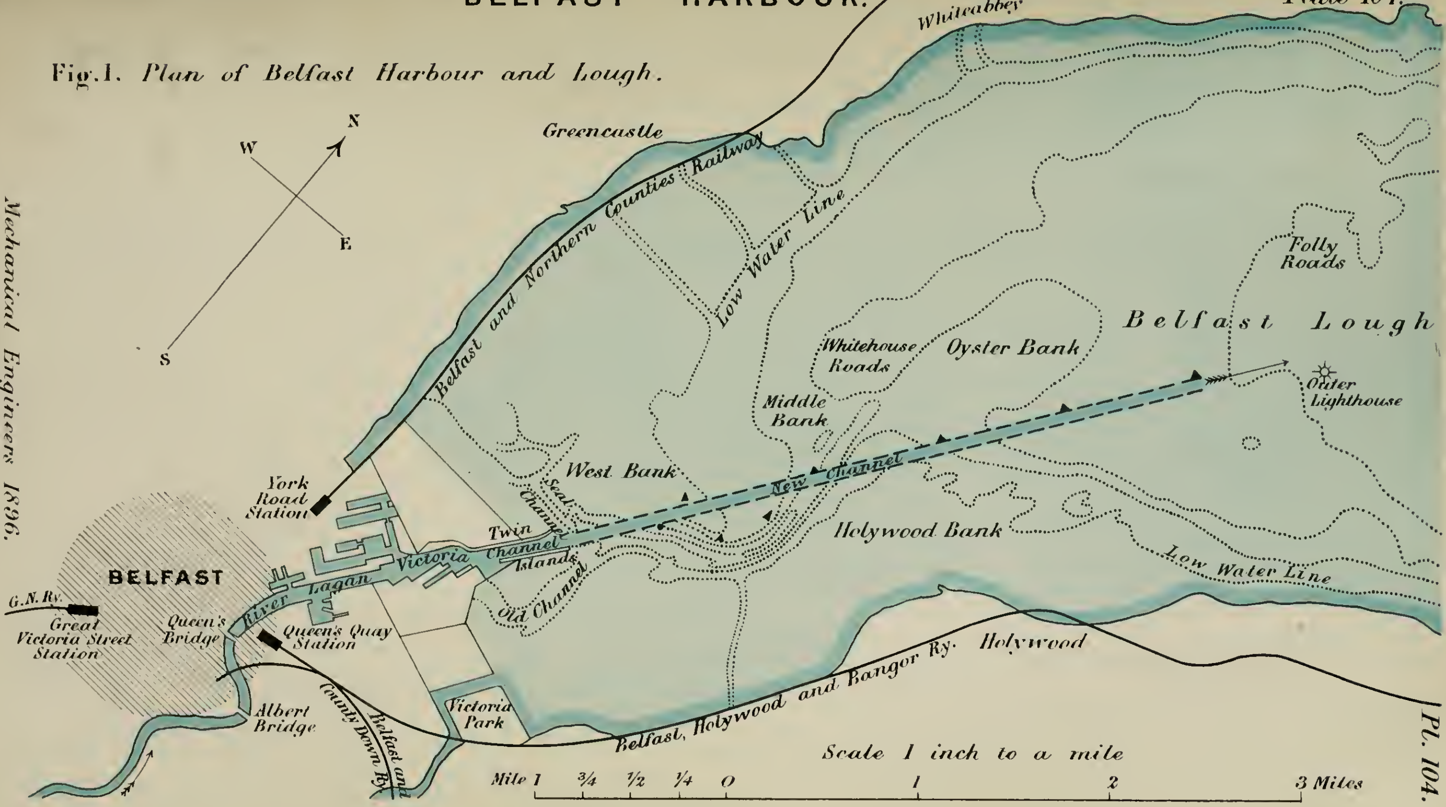
Fig. 7. *Water Gas Apparatus.*

Scale 1/144th

Scale 1/144th

BELFAST HARBOUR.

Fig.1. *Plan of Belfast Harbour and Lough.*



Mechanical Engineers 1896.

BELFAST HARBOUR.

Fig. 2. *Plan of Belfast Harbour and Docks.*

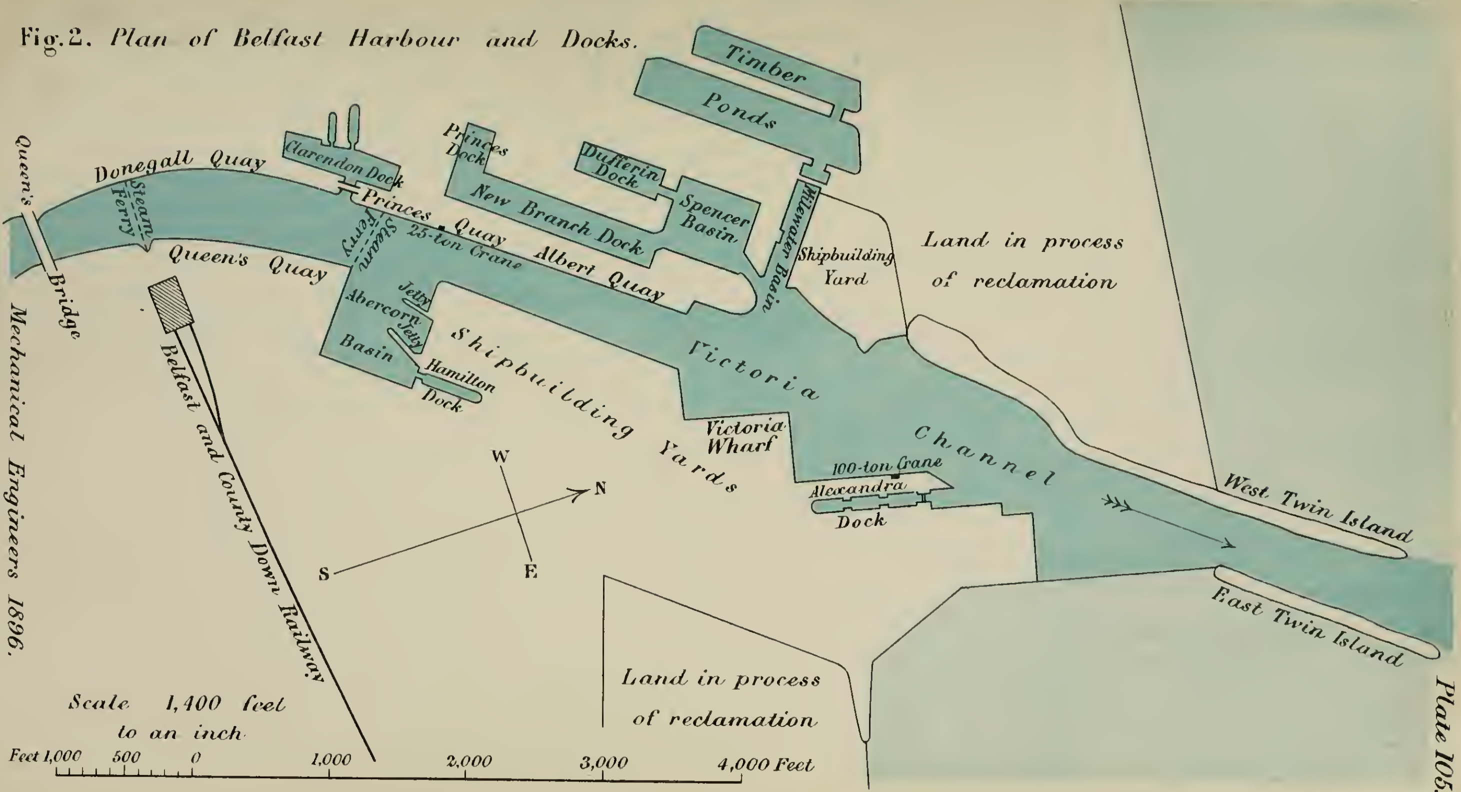
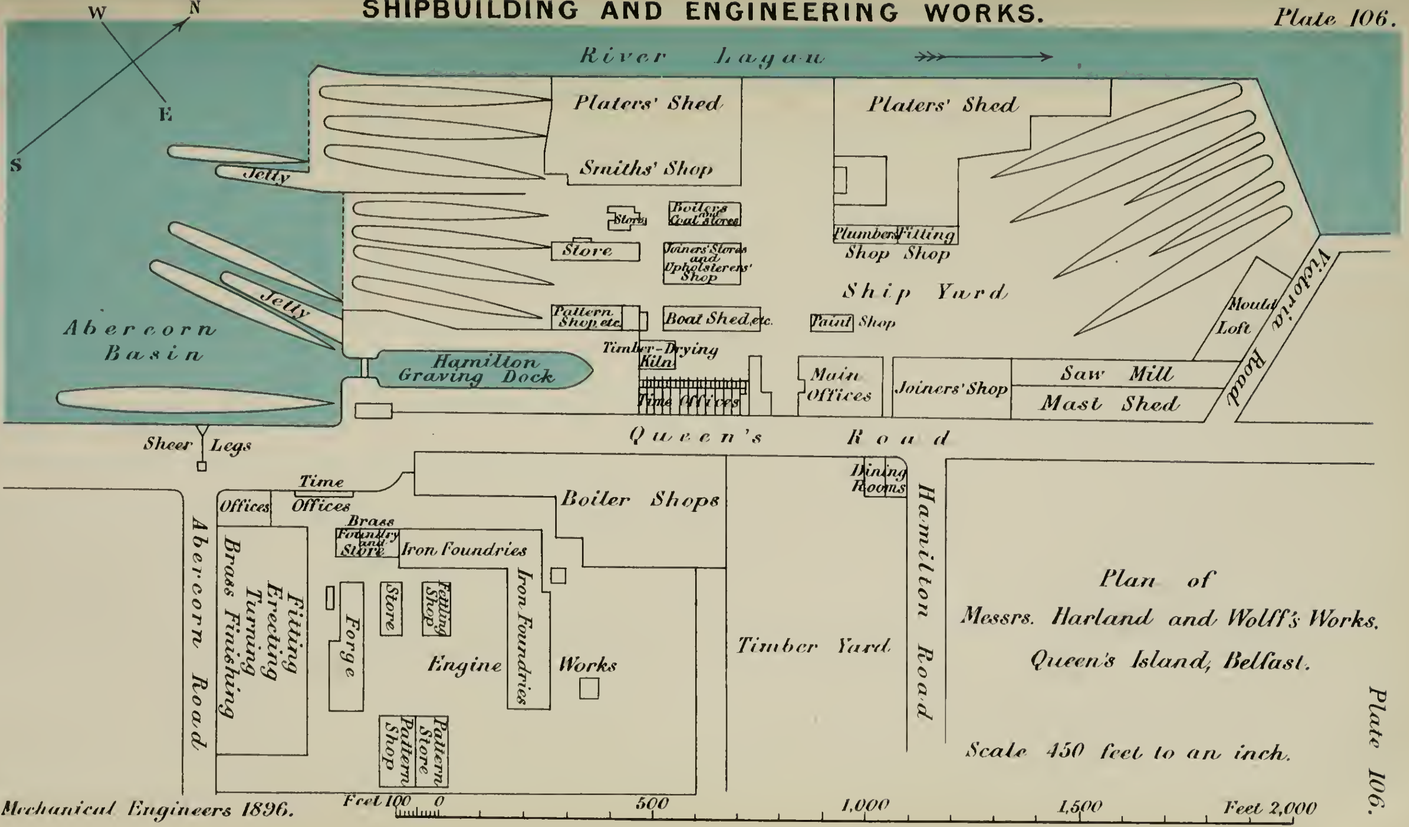


Plate 105.

SHIPBUILDING AND ENGINEERING WORKS.



Plan of
Messrs. Harland and Wolff's Works.
Queen's Island, Belfast.

Scale 450 feet to an inch.

Institution of Mechanical Engineers.

PROCEEDINGS.

November 1896.

The Autumn Meeting of the Institution was held in the rooms of the Institution of Civil Engineers, London, on Wednesday, 4th November 1896, at Half-past Seven o'clock p.m.; E. Windsor Richards, Esq., President, in the chair.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President announced that the Council had decided to mark their appreciation of the valued aid received from the Honorary Secretaries at the recent successful Summer Meeting in Belfast, by presenting a Silver Salver, suitably inscribed, to Mr. Bowman Malcolm, to Mr. A. Basil Wilson, and to Mr. Robert Meyer. The salvers were now on the table for inspection by the Members.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and that the following forty-four candidates were found to be duly elected:—

MEMBERS.

Burstall, Frederic William,	Birmingham.
Claremont, Ernest Alexander,	Manchester.
Clark, Thomas Forster,	London.
Cowdell, Henry Charles,	Cradley Heath.
Graham, Robert,	Ponce, Porto Rico.

Handyside, Charles Baird,	London.
Higby, Robert George,	Sitarampur.
Hitchcock, Cyril,	Lahore.
House, Henry Alonzo,	Bridgeport, U.S.
Markwick, Alfred Ernest,	Karachi.
Merrifield, Leonard Lancaster,	London.
Sennett, Alfred Richard,	London.
Smith, Roger Thomas,	Antwerp.
Spencer, Charles James,	London.
Tickner, Richard,	Karachi.

ASSOCIATE MEMBERS.

Abella, Juan,	Buenos Aires.
Adams, George,	London.
Bremner-Davis, William Joseph,	Manchester.
Comerford, Edward,	Liverpool.
Davis, Francis Myddleton,	Elizabethgrad.
Dowson, Erasmus Charles Head,	Toronto.
Garratt, Herbert Alfred,	London.
Issigonis, George Demos,	Smyrna.
Johnson, Andrew,	Glasgow.
Lovell, Samuel George,	London.
Mitton, Thomas Evans,	Birmingham.
Moncrieff, Robert Wighton,	Northampton.
Parker, John,	Manchester.
Pendred, Loughnan St. Lawrence,	London.
Rothery, William Brockbank,	Kirkby-in-Furness.
Swallow, John,	St. Helen's.
Turner, James William,	London.

ASSOCIATES.

Hutton, William,	Johannesburg.
King, Benjamin Thomas,	London.
Lemkes, Carl Rudolf Lewin,	Glasgow.
Marshall, Lewis,	Halifax.
Naylor, Sam,	Halifax.
Sangster, William Skene,	Lima.

GRADUATES.

Edwards, James George Benjamin,	Grimsby.
Fiegehen, Edward George,	Bedford.
Humphrey, Frederick George,	Sevenoaks.
Knight, Stephenson Yates,	London.
Williams, Llewellyn Wynn,	Glasgow.
Winlaw, William Willoughby,	Newcastle-on-Tyne.

The President announced that, in accordance with the Rules of the Institution, the President, two Vice-Presidents, and five Members of Council, would retire at the ensuing Annual General Meeting; and the list of those retiring was as follows:—

PRESIDENT.

E. Windsor Richards,	Low Moor.

VICE-PRESIDENTS.

Edward P. Martin,	Dowlais.
J. Hartley Wicksteed,	Leeds.

MEMBERS OF COUNCIL.

Benjamin A. Dobson,	Bolton.
Henry D. Marshall,	Gainsborough.
James Platt,	Gloucester.
T. Hurry Riches,	Cardiff.
Sir William H. White, K.C.B., LL.D., F.R.S.,	London.

All of the above offered themselves for re-election.

The following nominations had also been made by the Council for the election at the Annual General Meeting:—

Election as Member.	MEMBERS OF COUNCIL.	
1875.	Edward B. Ellington,	London.
1876.	Louis Sterne,	London.
1876.	John I. Thornycroft, F.R.S.,	London.

The PRESIDENT reminded the Meeting that according to the Rules of the Institution any Member or Associate Member was now entitled to add to the list of candidates.

No other names being added, the President announced that the foregoing would constitute the nomination list for the election of officers at the Annual General Meeting.

The following Papers were then read and discussed :—

"Research Committee on the Value of the Steam-Jacket; Experiment on a Locomotive Engine." By Professor T. HUDSON BEARE, F.R.S.E., and Mr. BRYAN DONKIN.

"Transmission of Heat from Surface Condensation through Metal Cylinders." By Lt.-Colonel ENGLISH and Mr. BRYAN DONKIN.

At a Quarter to Ten o'clock the Meeting was adjourned to the following evening. The attendance was 86 Members and 60 Visitors.

The ADJOURNED MEETING was held at the Institution of Civil Engineers, London, on Thursday, 5th November 1896, at Half-past Seven o'clock p.m.; E. WINDSOR RICHARDS, Esq., President, in the chair.

The following Paper was read and discussed :—

"Breakdowns of Stationary Steam-Engines." By Mr. MICHAEL LONGRIDGE, of Manchester.

On the motion of the President a vote of thanks was unanimously passed to the Institution of Civil Engineers for their kindness in allowing the use of their rooms for the Meeting of this Institution.

The Meeting then terminated at a Quarter to Ten o'clock. The attendance was 70 Members and 62 Visitors.

RESEARCH COMMITTEE ON THE VALUE OF THE STEAM-JACKET.

Mr. HENRY DAVEY, *Chairman.*

No. 66.—Experiment on a Locomotive Engine, By Professor T. Hudson Beare and Mr. Bryan Donkin.

Object of Experiment.—The object of this experiment was to ascertain the advantage gained by jacketing the cylinders of a locomotive engine. The trials were undertaken, and carried out on the Lancashire and Yorkshire Railway, at the suggestion of Mr. John A. F. Aspinall, Chief Mechanical Engineer, who gave every assistance to the experimenters. The latter were on the locomotive during the trials, as well as several assistants who were taking indicator diagrams and other data.

Owing to the fact that these trials were carried out on a locomotive doing its ordinary train service, it was impossible to obtain results as complete and thorough as would have been aimed at, had the experimenters been able to make the trials on a special train, the working of which could have been arranged to meet the necessities of the experiment. The trials were of short duration, and the condition of the fires at the start and the finish of each had to be determined by the necessities of the traffic requirements, and could not therefore be varied to suit the wishes of the experimenters. The consumption of steam was obtained with a close approach to absolute accuracy; but the same cannot be said respecting the fuel consumption, owing to the above circumstance with regard to the condition of the fires. The results obtained are therefore not such as will enable any definite conclusions to be drawn as to the value of the steam-jacket in locomotives. They are nevertheless interesting and valuable; and having involved considerable trouble on the part both of the experimenters during the trials and of Mr. Aspinall in the preparation of the engine for the experiment, it has been thought advisable to publish them for the use of the Members.

Description of Engine.—The experiment was made on a passenger locomotive, No. 1093, during its regular work of taking the 7.30 a.m. express train from Manchester to York, a distance of 76½ miles, and returning with the 3.0 p.m. express from York to Manchester. Both engine and tender are the ordinary standard pattern of this railway. As illustrated in Plates 107 to 110, the engine is a four-wheel coupled with bogie truck, the driving wheels being 7 ft. 1 in. diameter and the bogie wheels 3 ft. 0½ in. The cylinders are inside and horizontal, with their valve-chests on the top. The engine wheel-base is 21 ft. 6½ ins., and the total wheel-base of engine and tender 41 ft. 1½ ins. The weight of engine and tender when empty is 56·287 tons, and when in working order 70·925 tons, the tender carrying 1,800 gallons of water. The boiler is of steel, 4 ft. 2 ins. diameter and 10 ft. 7⅝ ins. long; the fire-box shell of steel, and the fire-box of copper, 6 ft. long, 4 ft. 1 in. wide, and 5 ft. 10 ins. high. There are 220 tubes of 1¾ inch outside diameter. The heating surface in the tubes is 1,108·73 sq. ft., and in the fire-box 107·68 sq. ft.; total 1,216·41 sq. ft. The fire-grate area is 18·75 sq. ft., the ratio of heating surface to grate area being 65 to 1. The fire-brick arch in the combustion chamber is about 2½ ft. long. The height of the chimney above the fire-grate level is 10 ft.

The cylinders were originally of the normal pattern, 19 inches diameter and 26 inches stroke. For this experiment they had been bored out and fitted with cast-iron liners, which reduced the internal diameter to 17½ inches, thus providing a body jacket of 3–8ths inch space. The front cylinder covers were fitted with external covers, the space between the two forming a steam-jacket. The back covers however were imperfectly jacketed by fitting over them, as close to the actual covers as possible, an annular wrought-iron ring with an inner and an outer cover, the space between the two latter forming a jacket space. The external surfaces of the end jackets were much exposed, and not well covered. In the diagrams Figs. 7 to 9, Plates 111 and 112, are shown sectional views of the cylinders as thus fitted with their jackets.

In Table 1 (page 473) are shown the clearance volumes of the cylinders, and the jacketed and unjacketed internal surfaces exposed to steam in the clearances alone, and also in the clearances and cylinders at 90 per cent. of the stroke. It will be seen that the proportion of the clearance surface jacketed is only about a quarter of the whole, and this is mainly due to the cover jackets; of the back ends therefore a large part is hardly jacketed at all, in the true sense of the word.

Description of Trials.—Four trials were made, lettered A B C D, on 18th and 19th September 1894: A unjacketed and B jacketed on the 18th; C jacketed and D unjacketed on the 19th. A and C were made on the runs from Manchester to York, and B and D on the return runs from York to Manchester. See Tables 2 and 3, pages 474–7.

Observations.—In each trial the weights of coal and feed-water consumed were measured, and readings of the various gauges were taken, and the position of the reversing gear was noted. Indicator diagrams were obtained, and in trials C and D samples of the furnace gases were collected from the smoke-box below the exhaust pipe.

Coal.—The coal used in the trials was from the Mitchell Main Colliery, Wombwell, near Barnsley. Samples were taken from each sack used, and were submitted to Mr. Charles J. Wilson for determining the calorific value in a calorimeter. The mean value from his tests was 14,200 thermal units per pound of dry coal, equivalent to an evaporation of 14·7 lbs. of water from and at 212° Fahr. The coal was placed on the tender in sacks holding 200 lbs. each; and the time of emptying each sack upon the footplate was noted, as well as the total weights. An attempt was made to have the fire in the same condition at the end of each run as at the start; but it was difficult to carry out this arrangement, since the trials were made during ordinary runs, and could not be allowed to interfere in any way with the regular working of the traffic. The gradients at the two ends of the journey are different, as seen in the profile of the line, Fig. 16, Plate 115; and different fires were therefore needed to ensure adequate steam at the beginning and end of each run.

The ashes and clinkers from the smoke-box and fire-box were weighed off at the end of each run, but those in the ashpan were weighed only at the end of each double journey. As each trial lasted only about two hours, errors introduced by variation in the condition of the fire might be thought to bear rather a large proportion to the total coal consumption; but, bearing in mind the rapidity of consumption, amounting to about 50 or 60 lbs. per square foot of grate per hour, this was probably not the case.

The actual coal consumption per indicated horse-power per hour of steaming time in the four journeys was respectively 2·87, 3·07, 2·73, and 2·79 lbs. In Fig. 10, Plate 112, is plotted the coal consumption in each of the four trials.

Furnace Gases and Temperatures.—On the first day no attempt was made to collect the gases; and as the thermometer for taking their temperature had been fixed above the blast-pipe orifice, Plates 109 and 110, it was not thought worth while to note its readings. On the second day the gases were collected continuously; but the thermometer, placed in a better position, unfortunately broke almost immediately after leaving Manchester, so that the temperatures could not be ascertained.

The difficult operation of collecting the gases while going at express speed was carried out by Mr. Michael Longridge. They were drawn off through a $\frac{1}{4}$-inch copper pipe, and then through a rubber pipe into a gasometer containing water, whilst a branch pipe led to a collecting bottle filled with mercury. After drawing off all the air in the pipe connections, the cock on the branch was opened, so that part of the current of waste gases passing to the gasometer could be diverted and collected by displacement over mercury in the collecting bottle. During the outward journey C much trouble was experienced, owing to the heavy chimney-blast; but in the return journey D everything worked quite satisfactorily.

The mean results of the three analyses made from the sample collected on each journey are the following volumetric percentages:—trial C, carbonic acid 12·85 per cent., oxygen 4·15, carbonic oxide 0·80, nitrogen 82·20; trial D, carbonic acid 15·10, oxygen 1·97, carbonic oxide 0·85, nitrogen 82·08 per cent.

Feed Water.—As arranged by Mr. Aspinall, the feed-water was measured by means of a Siemens water meter M on the pipe between the tender and the injector, Figs. 2 and 4, Plates 107 and 108. It was originally intended to have a means of making direct measurement of the feed-water; but he had not been able to carry out the necessary arrangements. The meter was read at the time of starting from each station, and thus a fair approximation to the rate of consumption was obtained, as well as the total quantity. The overflow from the injector was caught and allowed for.

After the trials were over, the meter was sent to University College, London, and tested there by Professor Beare at rates of flow similar to those in the trials. The error was somewhat variable, but the meter was found to be registering on the average 2·6 per cent. too low. In order to be able to correct for differences of level in the boiler, the quantity passing through the meter to raise the level in the gauge glasses one inch, for each inch in their height with the engine standing under full steam, was determined by Mr. Donkin after the trials.

Steam-Jacket Water.—The jackets were drained into three small tanks T, Figs. 1 and 5, Plates 107 and 109, carried upon a temporary staging on the front of the engine; one measurement was made for the two body jackets together, another for the two front covers, and a third for the two back covers. While standing at York on each day radiation tests were made, by measuring the quantity of steam condensed in each pair of jackets with the engine standing, all hot; these lasted 2½ hours on the first day, and 1½ hours on the second. The following were the results obtained:—

Condensation of Steam in Jackets, lbs. per hour.

	While running.		While standing.	
	Sep. 18, B.	Sep. 19, C.	Sep. 18.	Sep. 19.
Two Body Jackets .	267	241	35·0	26·7
Two Front Covers .	123	103	16·0	13·7
Two Back Covers .	65	55	12·0	15·8

Times, Pressures, &c.—The times of passing all the stations were noted; and also the times during which the steam was shut off, in order to determine the actual running time and the actual steaming time in each trial. Whenever a set of indicator diagrams was taken, a note was made of the boiler pressure, of the pressure in the jackets, of the position of the reversing gear, and also of the gradient and mileage.

Indicator Diagrams.—These were taken simultaneously from both ends of each cylinder; those nearest the mean in each of the four trials are shown in Figs. 11 to 14, Plates 113 and 114. The springs of the indicators used were not tested for errors, since these would not affect the comparative results of the four trials. In Tables 4 to 7 (pages 478–481) are given the times of taking the diagrams, and also the speed of train and other particulars. Unfortunately no counter was fixed for the trials, as had been intended. The speed in miles per hour was continuously registered by a Boyer speed recorder R, Figs. 2 and 6, Plates 107 and 110, kindly lent by Mr. Aspinall, upon a paper wound on a drum which was driven from the rear bogie axle. A diagram of the curves obtained is shown in Fig. 15, Plate 115. If this instrument recorded correctly, the circumference of the driving wheels being known and all slip neglected, the revolutions per minute of the driving wheels can be calculated. An attempt was made to count the revolutions at the time the diagrams were being taken; but it was found impossible to do this correctly at the high speeds. After much deliberation, it was decided to make a series of tests of the Boyer recorder, by driving it at known speeds, in order that any errors in the diagram it recorded might be ascertained. This was afterwards done by Mr. Donkin, and details of the method of testing are given in the appendix, page 482; the errors being plotted on a speed base, the error at any speed can easily be ascertained. In Tables 4 to 7 the revolutions per minute are the corrected values, while the miles per hour are the speeds actually registered by the recorder, and are therefore on the average some 2 or 3 per cent. too low. The indicated horse-power given in the tables is calculated from the revolutions obtained from the recorder, after correction for the error ascertained by the testing. Had a counter been fixed, it would have saved much trouble, and would have been much more satisfactory.

General Results.—Tables 2 and 3 (pages 474–477) give the mean results of all the important observations. Comparing trials A and C, both from Manchester to York, the jacketed trial C shows a consumption of 24·49 lbs. of steam per I.H.P. per hour, Table 3, line 16, against 26·70 lbs. for the non-jacketed run A, or a saving of 8·3 per cent. by jacketing. Comparing trials B and D, both from York to Manchester, the figures are 24·48 and 24·87 lbs. respectively, or a saving of 1·5 per cent. by jacketing. Comparing the figures for coal consumption in trials A and C, Table 2, line 17, the jacketed trial C shows an economy of 0·14 lb. per horse-power per hour, or practically 5 per cent., the increased consumption per train-mile in this run being accounted for by the greater load hauled; the load was 8 per cent. greater in C than in A, the average speed being nearly the same in both runs. Comparing trials B and D however, the jacketed trial B is distinctly less economical, the coal consumption being 0·28 lb. greater per horse-power per hour than in the non-jacketed trial, or 10 per cent. more; and the consumption is also greater per train-mile. In these two trials, while the weight of train hauled was the same, the speed was nearly 3 miles an hour greater in the non-jacketed run D, with a correspondingly much increased horse-power.

TABLE 1.—*Engine Dimensions.*

Diameters of Cylinders, taken hot.	right	inches	17·543
	left	inches	17·559
Diameter of Piston-rods		inches	2·95
Mean Areas of Pistons	right	square inches	238·31
	left	square inches	238·76
Stroke of Pistons		inches	26
Diameter of Driving Wheels on tread		inches	85
Cylinder constants for indicated horse-power per lb. of mean effective pressure at 1 revolution per minute	right	I.H.P.	0·031293
	left	I.H.P.	0·031352
Clearance Volumes*	front	cubic foot	0·293
	back	cubic foot	0·247
	mean	cubic foot	0·270
Mean Clearance Volume in inches of stroke		inches	1·96
,, ,, ,, in percentage of piston displacement		per cent.	7·52
Volume of Steam at 90 per cent of stroke, mean of both cylinders, including clearance		cubic feet	3·500

Internal Surfaces exposed to Steam.

Mean of both cylinders and of front and back		Jacketed	Non-Jacketed	Total.
Clearance	square feet	2·56	6·78	9·34
	per cent.	27·4	72·6	100·0
Clearance plus Cylinder at 90 per cent. of stroke	square feet	10·46	8·18	18·64
	per cent.	56·1	43·9	100·0

* Mean of both cylinders, obtained by filling with water the calculated volumes came 2 per cent. higher.

TABLE 2.—*Boiler Results.*

1	Trial		A	B	C	D
2	Date of trial, 1894 September		18	18	19	19
3	Journey		Manchester to York	York to Manchester	Manchester to York	York to Manchester
4	WITH or WITHOUT all Steam-Jackets		WITHOUT	WITH	WITH	WITHOUT
5	Duration of trial, station to station	minutes	134½	108	134	99½
6	Total running time, excluding stops	minutes	111	97½	113	92
7	Total time steam was on	minutes	95	83	93	78
8	Total Load, including engine and tender	tons	173	171	187	171
9	Average Speed while running	miles per hour	41·3	47·1	40·6	49·9
	Mean Steam Pressure per square inch above atmosphere.					
10	In boiler	lbs.	156	162	158	160
11	In barrel jackets	lbs.	—	149	147	—
12	In front-cover jackets	lbs.	—	149	147	—
13	In back-cover ,,	lbs.	—	149	147	—

TABLE 2 (*continued*).

	Coal Consumption.	trial	A	B	C	D
14	Total during trial (see Fig. 10, Plate 112)	lbs.	2,211	2,160	2,400	2,050
15	Per hour of total time	lbs.	986	1,200	1,075	1,236
16	Per square foot of fire-grate per hour	lbs.	52·6	64·0	57·3	65·9
17	Per I.H.P. per hour of steaming time	lbs.	2·87	3·07	2·73	2·79
18	Per train-mile	lbs.	28·9	28·2	31·4	26·8
19	Ashes and clinker, total	lbs.	389	494	320	454
20	,, ,, ,, percentage of coal	per cent.	17·6	22·9	13·3	22·1
	Feed-water Consumption.					
21	Temperature	Fahr.	55°	56½°	57°	58°
22	Total, corrected for boiler level and meter	lbs.	20,580	17,190	21,500	18,260
23	Per hour of total time	lbs.	9,180	9,550	9,625	11,010
24	Per square foot of heating surface per hour	lbs.	7·55	7·85	7·91	9·05
25	Per pound of coal	lbs.	9·31	7·96	8·96	8·91
26	,, ,, ,, from and at 212° F.	lbs.	11·28	9·64	10·85	10·78
27	Calorific Value of Coal, water evaporated per pound from and at 212° F.	lbs.	14·7	14·7	14·7	14·7
28	Thermal Efficiency of boiler, 100 × line 26 ÷ line 27	per cent.	76·7	65 6	73·8	73·3

TABLE 3.—*Engine Results.*

1	Trial letter		A	B	C	D
2	Date of trial, 1894 September		18	18	19	19
3	Journey		Manchester to York	York to Manchester	Manchester to York	York to Manchester
4	WITH or WITHOUT all Steam-Jackets		WITHOUT	WITH	WITH	WITHOUT
5	Condition of Rails, dry or wet		dry	dry	wet	dry
6	Wind		moderate	moderate	strong	moderate
7	Air Temperature, average	Fahr.	58°	58°	57°	57°
8	Mean Revolutions per minute, at time of taking indicator diagrams	revs.	187·8	188·2	198·7	224·3
9	Mean Effective Pressure per square inch, from indicator diagrams, right	lbs.	44·87	47·78	51·20	44·57
	" " left	lbs.	40·24	44·11	43·86	38·38
10	Mean Indicated Horse-power, right	I.H.P.	255·9	263·9	305·6	301·5
11	" " " left	I.H.P.	230·9	243·4	260·8	263·2
12	" " " total	I.H.P.	486·8	507·3	566·4	564·7

TABLE 3 (*continued*).

	Steam Consumption.	trial	A	B	C	D
13	Total, including jackets	lbs.	20,580	17,190	21,500	18,260
14	Total time of steam in cylinders	hour	1·583	1·383	1·550	1·300
15	Steam per hour of steaming time	lbs.	13,000	12,430	13,870	14,050
16	,, ,, ,, ,, ,, per I.H.P.	lbs.	26·70	24·48	24·49	24·87
17	Economy due to Jackets, percentage less steam	per cent.		1·5	8·3	
	Jacket Water.					
18	Two barrel jackets, total	lbs.		370	357	
19	Two front covers ,,	lbs.		170	160	
20	Two back covers ,,	lbs.		90	85	
21	Jacket Water, total	lbs.		630	602	
22	,, ,, per hour of steaming time	lbs.		455	388	
23	,, ,, ,, ,, ,, ,, ,, per I.H.P.	lbs.		0·897	0·686	
24	Percentage of feed-water, 100 × line 21 ÷ line 13	per cent.		3·7	2·8	

TABLE 4.—*Trial A. Manchester to York. Tuesday* 18 *September* 1894.

Without *Steam in Jackets.*

No. of Diagram.	Time.	Gradient.	Speed.		Steam cut off.	Mean Effective Pressure per sq. inch.		Indicated Horse-power.	
			Revolutions per minute.	Miles per hour.		Right.	Left.	Right.	Left.
			Revs.	Miles.	Per cent.	Lbs.	Lbs.	I.H.P.	I.H.P.
1	Not taken.	1 in 150 rising	119·0	32	45	71·8	58·0	267·4	216·4
2		1 ,, 1,056 ,,	140·2	37	40	51·7	47·0	226·8	206·6
3		1 ,, 161 ,,	161·2	42	35	53·8	49·9	271·4	252·2
4		level	161·2	42	25	34·5	30·7	174·0	155·2
5		1 in 183 falling	182·6	47	17	24·3	20·6	138·8	118·0
6		1 ,, 183 ,,	230·0	58	20	30·0	29·4	216·0	212·0
7		1 ,, 377 ,,	131·6	35	25	45·1	40·0	185·7	165·0
8		1 ,, 528 ,,	212·7	54	25	37·6	33·5	250·3	223·4
9		1 ,, 440 ,,	212·7	51	35	59·0	52·2	392·7	348·1
10		1 ,, 440 ,,	238·6	60	25	35·1	31·5	262·1	235·6
11		1 ,, 528 ,,	281·3	70	25	37·4	32·9	329·2	290·1
12		1 ,, 330 ,,	161·2	42	35	60·0	51·5	302·7	260·3
13		1 ,, 330 rising	187·0	48	25	40·4	38·7	236·4	226·9
14		1 ,, 3,153 ,,	191·4	49	30	45·0	41·0	269·5	246·0
15		1 ,, 3,162 falling	174·0	45	30	47·2	44·0	257·0	210·0
16		1 ,, 1,175 rising	178·3	46	30	47·3	43·9	263·9	245·4
17		level	230·0	58	30	42·5	39·3	305·9	283·4
	Means		187·8	48·2		44·87	40·24	255·9	230·9
							Total	486·8	

Moderate wind; rails dry.

TABLE 5.—*Trial B. York to Manchester. Tuesday 18 September* 1894.

WITH *Steam in Jackets.*

No. of Diagram.	Time.	Gradient.	Speed.		Steam cut off.	Mean Effective Pressure per sq. inch.		Indicated Horse-power.	
			Revolutions per minute.	Miles per hour.		Right.	Left.	Right.	Left.
	p.m.		Revs.	Miles.	Per cent.	Lbs.	Lbs.	I.H.P.	I.H.P.
1	—	level	156·9	41	35	62·1	56·1	304·9	276·0
2	3-12	1 in 1,175 falling	182·6	47	30	53·0	48·1	302·9	275·4
3	3-17	1 ,, 10,560 rising	225·6	57	30	40·9	36·6	288·7	258·9
4	3-20	1 ,, 631 ,,	242·8	61	30	43·0	39·0	326·7	297·0
5	3-29	1 ,, 3,153 falling	52·1	15	35	78·4	72·4	127·8	118·3
6	3-38½	1 ,, 330 rising	187·0	48	30	45·7	44·9	267·5	263·2
7	3-46	level	110·7	30	40	74·5	71·4	258·1	247·8
8	3-49	1 in 660 rising	221·3	56	30	43·0	38·7	297·8	268·5
9	3-54	1 ,, 440 ,,	208·5	53	25	41·2	35·3	268·8	230·8
10	3-59	1 ,, 440 ,,	208·5	53	25	41·0	36·6	267·5	239·3
11	4- 3½	1 ,, 528 ,,	204·2	52	30	44·1	40·6	281·8	260·0
12	4- 9	1 ,, 377 ,,	230·0	58	30	41·5	39·2	298·7	282·7
13	4-14	1 ,, 183 ,,	204·2	52	30	41·7	40·9	266·5	261·9
14	4-25	level	178·3	46	25	37·0	35·0	206·5	195·7
15	4-31	1 in 330 falling	208·5	53	20	29·7	26·8	193·8	175·2
	Means . . .		188·1	48·1		47·78	44·11	263·9	243·4
							Total	507·3	

Moderate wind; rails dry.

TABLE 6.—*Trial C. Manchester to York. Wednesday* 19 *September* 1894.

WITH *Steam in Jackets.*

No. of Diagram.	Time.	Gradient.	Speed.		Steam cut off.	Mean Effective Pressure per sq. inch.		Indicated Horse-power.	
			Revolutions per minute.	Miles per hour.		Right.	Left.	Right.	Left.
	a.m.		Revs.	Miles.	Per cent.	Lbs.	Lbs.	I.H.P.	I.H.P.
1	7–52	1 in 150 rising	119·0	32	35	86·4	76·6	321·7	285·8
2	8– 4	1 „ 161 „	178·3	46	35	63·4	58·6	353·7	327·6
3	8– 8	level	204·2	52	25	48·3	40·2	308·7	257·4
4	8–18	1 in 183 falling	208·5	53	17	26·0	20·4	169·6	133·4
5	8–21	1 „ 183 „	225·6	57	17	22·3	14·9	157·4	105·4
6	8–36	1 „ 377 „	200·0	51	25	48·0	41·3	300·5	259·0
7	8–50	1 „ 410 „	230·0	58	30	49·3	42·4	354·9	305·8
8	8–57	1 „ 660 „	242·8	61	25	35·5	27·9	269·7	212·4
9	9–12	1 „ 330 „	169·7	41	35	68·8	63·2	365·4	336·3
10	9–21	1 „ 484 „	217·0	55	30	51·5	43·1	349·7	293·2
11	9–27	1 „ 3,153 rising	165·4	43	25	59·5	51·0	308·0	264·5
12	9–38½	1 „ 3,162 falling	204·2	52	35	60·4	52·2	386·0	334·2
13	9–47	1 „ 1,175 rising	195·8	50	25	51·7	42·7	316·8	262·1
14	9–51	level	221·3	56	25	45·7	39·5	316·5	274·1
Means . . .			198·7	50·7		51·20	43·86	305·6	260·8
							Total	566·4	

Strong head-wind; rails wet.

TABLE 7.—*Trial* D. *York to Manchester.* *Wednesday* 19 *September* 1894.

Without *Steam in Jackets.*

No. of Diagram.	Time.	Gradient.	Speed.		Steam cut off.	Mean Effective Pressure per sq. inch.		Indicated Horse-power.	
			Revolutions per minute.	Miles per hour.		Right.	Left.	Right.	Left.
	p.m.		Revs.	Miles.	Per cent.	Lbs.	Lbs.	I.H.P.	I.H.P.
1	2–58½	level	174·0	45	35	71·1	52·5	387·2	286·4
2	3– 1½	1 in 1,320 falling	221·3	56	25	45·5	41·3	315·1	286·6
3	3– 5	1 ,, 1,320 ,,	247·1	62	25	42·5	36·4	328·6	282·0
4	3– 8	1 ,, 3,078 ,,	255·6	64	25	39·4	35·8	315·1	286·9
5	3–12	1 ,, 3,162 rising	255·6	64	25	39·5	35·8	316·0	286·9
6	3–16	1 ,, 631 ,,	242·8	61			33·7		256·5
7					0	Steam	off		
8	3–28	1 in 484 rising	182·6	47	25	48·0	41·5	274·3	237·6
9	3–33½	1 ,, 330 ,,	161·2	42	35	66·3	53·3	334·5	269·4
10					0	Steam	off		
11	3–43	level	182·6	47	25	46·9	39·6	268·0	226·7
12	3–46	1 in 660 rising	225·6	57	25	42·5	37·3	300·0	263·8
13	3–49½	1 ,, 660 ,,	234·3	59	25	44·2	39·8	324·1	292·4
14	3–53½	1 ,, 440 ,,	247·1	62	30		39·4		305·2
15	3–57	1 ,, 440 ,,	238·6	60	25	41·8		312·1	
16	4– ½	1 ,, 377 ,,	234·3	59	25	42·7		313·1	
17	4– 5	1 ,, 377 ,,	225·6	57	25	43·9		310·0	
18	4– 8	1 ,, 183 ,,	221·3	56	25	43·5		301·2	
19	4–12	1 ,, 183 ,,	204·2	52	30	46·3		295·9	
20	4–20	1 ,, 330 falling	208·5	53	25	39·4	36·0	257·1	235·3
21	4–23½	1 ,, 330 ,,	251·3	63	25	37·5	34·5	294·9	271·8
22	4–28	1 ,, 161 ,,	272·7	68	17	21·2	18·8	180·9	160·7
Means			224·3	56·7		44·57	38·38	301·5	263·2
							Total	564·7	

Moderate wind; rails dry.

APPENDIX.

Testing of Boyer Speed Recorder.

The instrument used in the trials was afterwards tested at Bermondsey by Mr. Donkin in October 1894. It was driven by a small vertical engine, on the crank-shaft of which was a counter. The instrument is so constructed that when it is driven at 600 revolutions per minute the pencil should record a speed of 60 miles per hour on the paper. The circumference of the driving pulley on the instrument was 17·75 ins., and that of the engine pulley 44·75 ins., or a ratio of 1·000 to 2·521. The recorder being driven by a steel wire without slip, the revolutions per minute of the engine multiplied by 2·521 give the revolutions per minute of the recorder; and these divided by 10 give the calculated speed in miles per hour which the recorder should register. The difference between this calculated speed and the speed actually registered by the recorder is the error of the instrument. Altogether some fifteen tests were made, each of five minutes duration, during which the mean speed of the engine was taken by the counter, and compared with the mean speed registered by the recorder. The results of the tests showed that at about 15 miles per hour the instrument recorded about 10 per cent. too high, at 40 miles it recorded correctly, and at 60 to 80 miles per hour 4 per cent. too low. The errors when plotted on a base of speed form a regular curve, from which the following corrections have been taken :—

Speed, miles per hour . .	15	20	25	30	35	40	45	50	55	60	65
Error of Recorder, per cent.	10	7½	5½	3½	1½	0	1½	2½	3½	4	4½
	too high						*too low*				

Discussion.

Mr. John A. F. Aspinall, Member of Council, drew attention to the fact that the experiments described in the paper were tried as far back as September 1894. On the whole they were of value, he thought, rather because they served to show what ought to be done in any future experiments, than as having any immediate practical results. Before the experiments were tried by Professor Beare and Mr. Donkin, a number of runs had been made with the engine, and the figures then obtained agreed generally with those given in the paper. But the trials were a matter of great difficulty. The engine had to have three sets of measuring tanks in front of it, connected with the different steam-jackets; and all three had to be carefully watched, together with the indicators, the different pressure-gauges, the water-gauge registering the vacuum in the smoke-box, the water-meter between the engine and tender, and various other instruments; and at least half a dozen observers had to hang on as carefully as they could, while the engine was going at a considerable speed. It would thus be seen what real difficulty there was in conducting experiments of this kind, such as was not experienced with an ordinary stationary engine. Such experiments ought indeed to be tried upon a line going through a district where there were not many signals and not much to trouble the driver; and not upon such a line as that on which the present trials had been made, where on 500 miles of railway there were no less than 800 signal boxes.

With the remark in page 466, about the condition of the fires not suiting the wishes of the experimenters, he did not altogether agree. The conditions of the experiments he held ought not to be varied to suit the wishes of the experimenters, but the latter should accept the ordinary conditions of locomotive running; because the object was to see whether putting steam-jackets upon an engine was of any advantage or not, and the commercial advantage would be proved by the engine doing well under ordinary conditions of running.

Again, the figures given in page 469 for the coal consumption per indicated horse-power per hour of steaming time in the four several journeys, he thought could not be taken as reliable. This opinion

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he held without thereby casting any reflection upon the observers, to whom his thanks were due for the way in which they had conducted the experiments: but simply because it had been found immediately after the trials that the indicator diagrams exhibited—and bad diagrams indeed it would be agreed they were—had been made of the shape shown on account of the presence of water in the indicator pipes. That had been a source of endless trouble. Recently he had been trying some experiments with indicators put right on the ends of the cylinders, with the shortest possible steam-pipes. The area of the diagrams so taken was thereby increased largely, and the initial pressure approached almost exactly to the steam-chest pressure or the boiler pressure. The result of the inaccuracy of the indicator diagrams which accompanied the paper was that the figures deduced from them in the paper were perforce inaccurate also.

In page 470 it was mentioned that it had originally been intended to have a means of making direct measurement of the feed-water, but that he himself had not been able to carry out the necessary arrangements. The original idea of the experimenters, so far as he remembered, had been that the tender should be marked off with horizontal lines to show the number of gallons it contained for each inch of depth; and that the consumption of water should be read off in that way. But a meter he thought was a much better and a much more positive way of ascertaining it than by trying to measure the water in the tender, because of the surging backwards and forwards which took place when the engine was running. Moreover the latter method was rendered more difficult, because water had to be picked up from track troughs more than once on each journey.

From page 471 it appeared that the experimenters would have preferred a counter, instead of a Boyer speed recorder. The latter however, enabling the speed to be seen at the instant of taking the indicator diagrams, he thought was a better instrument than a counter, which counted the revolutions not only during the short time of taking the diagrams, but also for a long time before and after they were taken, and from which therefore only a mean result could be obtained. If the Boyer recorder had been used in the way in which he thought it could have been, it would have been easy for one of the observers to mark at once upon it the times at which the diagrams were taken, and thereby the speed would have been exactly recorded.

The remarks he had already made with regard to the figures of coal consumption in page 469 applied also to those in page 472, which were vitiated by the inaccuracy of the indicator diagrams; and he was reminded of a saying that, next to an ammeter, no instrument could give such false results as a steam-engine indicator.

The engine had continued running with the steam-jackets since the experiments had been tried, and on the whole it had shown economy; but he was not yet prepared to say what the actual economy was, because all such matters required to be tried with the greatest possible care. It was so difficult to be certain as to the results obtained from a single locomotive, that in experiments of this kind, when the figures seemed to point to success, he was always tempted to doubt them more than ever, because it was necessary to take into consideration questions of load, of wind and weather, and of other matters, which never arose with a stationary engine. While he thought there had been an economy in the use of the steam-jackets, he might mention that in some other experiments, in which he had tried drawing the hot smoke-box gases round the cylinders, whereby the temperature in the jackets rose as high as about 470° Fahr., he had met with contrary results, and had not got the economy he had expected. He therefore looked upon all the experiments tried up to the present time as only indicating how much more care ought still to be taken, before it could be stated positively that the results were good.

Mr. David Joy mentioned that from experiments made on the *Aberdeen* steamship, which had been carefully carried out and reported to the Institution of Naval Architects (Transactions 1882, vol. xxiii, page 33), no definite conclusion could be arrived at; they had been much like the present experiments in not showing which way the result was—whether there was any advantage or not in steam-jacketing.

Mr. Samuel W. Johnson, Vice-President, enquired whether, notwithstanding the admitted unreliability of the trials recorded, the use of steam-jackets had so far commended itself to Mr. Aspinall that he contemplated altering all his engines to it. No doubt the difficulties of making such experiments were great; and it seemed to him that the results of those recorded in the paper must necessarily be unreliable. The statement of steam and coal consumption in page 472 he thought was rather misleading, because the differences in load and speed and other conditions would themselves be sufficient to make all the difference in consumption. In trials of this kind on a railway the great difficulty lay in getting the engine making the experiments to take a train under precisely the same conditions in the successive trials. The value of the steam-jacket on a locomotive engine he thought was perhaps small, compared with the ordinary method of keeping the cylinders warm either by the hot-air of the smoke-box or by a wood lagging, or by simply a lagging of sheet-iron with a space of air between.

Mr. Michael Longridge, while agreeing that the paper was certainly to some extent a record of failure to ascertain facts, thought there were great excuses to be made for the failure; for no one who had not made a locomotive trial could have any conception of what the difficulties really were. Nevertheless he considered the paper valuable, because he thought it taught an important lesson. With regard to the value of the steam-jacket, he was afraid it told absolutely nothing. It was quite true that in the first pair of trials compared in page 472, A and C, there was a difference of 8·3 per cent. in the steam consumption, in favour of jacketing; but he was afraid that this was rather due to errors of observation than an absolute fact, for in trials B and D the saving was only 1·5 per cent. If it was considered that the engine was running almost in the same way, and at nearly the same load, and over the same line, there was no apparent reason why the steam consumption should be 7 per cent. greater in the one case than in the other. Then going a step further, and looking at the quantity of steam used in comparison with the coal burnt, it would be noticed that on the first day the rate of evaporation must have been such as could hardly be credited. From line 26 in Table 2 it would seem as though in trial A there had been an evaporation of 11·28 lbs. of water per pound of coal; but this did not at all represent the real fact, because from line 20 it would be seen that in the two trials on that day the weight of the ashes and clinkers taken out of the ashpan and fire-box and smoke-box amounted to 17·6 per cent. in trial A and 22·9 per cent. in trial B. These figures however did not represent exactly the facts, because, as stated in page 469, the ashes from the ashpan were weighed only at the end of each double journey: so that on the whole it might be said that the ash made was about 20 per cent. in each trial, or about one-fifth of the entire weight of coal was taken out in ashes. If this were deducted, it would be found that there was an evaporation of 14·1 lbs. of water per pound of coal, which according to page 468 would be equivalent altogether to only 600 thermal units less than the total value of the coal, thus leaving only 600 units for the losses by imperfect combustion, radiation, and coal blown out of the chimney: which last he was sure was no inconsiderable quantity, for he had watched the chimney carefully himself, being in front of the engine all the time. It seemed therefore doubtful whether the reported water consumption of 26·7 lbs. per I.H.P. per hour in trial A was at all reliable; he was inclined to think it was over-estimated, and that the consumption was probably much the same in all the trials. With regard to the boiler moreover, it was difficult to rely upon the results exactly, because the quantity of coal in the fire-box at the beginning and at the end of the trial might easily have differed by an appreciable quantity without its being perceived. In a locomotive fire-box it was difficult, he thought, to estimate the thickness of the fire to within six inches; and if that were the case, the fire-box of the engine tried would hold some 270 lbs. of incandescent fuel in a thickness of six inches, which was about 12 per cent. of the total consumption of coal in each trial. But whether the results were reliable or not, their general tendency was to show a rate of evaporation far higher than was generally obtained in stationary boilers. On working out the figures he had found that the heat put

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into the water per pound of coal was 10,400 units. The heat equivalent of the unburnt carbon in the ashes he estimated at 1,400 units; for he was sure from what he knew of the coal used that it did not contain more than 7 per cent. of ash, and he had accordingly taken as unburnt carbon the difference between this 7 per cent. and the 17 per cent. mentioned in the paper. The imperfect combustion shown by the production of carbonic oxide, which he presumed was taking place while the engine was running without steam and with a thick fire, would cause a loss of about 400 units; and the mean quantity of heat taken up the chimney—assuming the temperature to be 800° F., which he thought it probably was, since it burst the thermometer, notwithstanding Mr. Aspinall's statement (page 485) of only 470°—would account for 2,500 units more. Altogether therefore 14,700 units would seem to have been got out of coal containing only 14,200. All this seemed to him to point indubitably to one fact, namely a considerable amount of priming. The lesson therefore which the trials taught was that, instead of putting steam-jackets on locomotive cylinders, a superheater ought to be put in the smoke-box. If this were done, and the priming water were turned into steam, he thought there would be a considerable economy, with little more weight to be carried than by steam-jacketing the cylinders.

Mr. Aspinall explained that the 470° F., which he had mentioned having obtained in the jackets from the hot smoke-box gases, had no relation to these particular experiments; it was only the result of some temperature measurements in another instance. No doubt Mr. Longridge's estimate of 800° was much nearer the mark for the temperature of the smoke-box in the experiments reported.

Mr. Johnson quite agreed with Mr. Longridge that it would be well if a locomotive could be tried with steam superheated. That there was some economy in steam-jacketed cylinders he did not in any way deny; but in a locomotive he was satisfied that it must be only a small percentage. A great deal of the difference in water consumption recorded in the tables arose he thought from saturated steam or from priming. The amounts of water per pound of coal burnt were in his opinion rather excessive; and superheating would tend greatly to do away with that source of loss.

Mr. Druitt Halpin considered the locomotive evaporation, commented upon by Mr. Longridge as so high, involved the question not only of the economy but also of the rate of evaporation. In a paper by his father, the late Mr. J. A. Longridge, eighteen years ago (Proceedings Inst. C.E., 1878, vol. lii, page 101), it had been shown conclusively that locomotive evaporations, both as to economy and as to speed of evaporation, were unsurpassed in any other boilers; the heat transmission was about 11 units per hour per square foot of heating surface per degree of difference in temperature, whereas in ordinary stationary boilers it was only about 5 or 6 units. It had always seemed to him that this was to be accounted for to a great extent by the fact that a locomotive boiler was in a condition which no other boiler was in, except perhaps that of a torpedo boat. The chatter that went on was exceedingly favourable to rapidity of heat transmission, from the fact that each nascent bubble of steam, no matter how small, was jarred off immediately it was formed; and the economy of evaporation was probably produced by the fact that from the same cause the fire was kept in such a lively state that each particle of carbon got its own proper particle of oxygen direct.

In these trials it would be noticed that there were water-traps as well as tanks on the platform on the front of the engine; but he did not know whether it could be hoped that water-traps placed above the level of the steam-jackets and exposed to such jolting would give any reliable results; of course if they had the effect of water-jacketing the cylinders, the difference from steam-jacketing would be great. The conflicting results reported were practically worthless in respect of economy, as he thought might be expected, because in order to derive any good from steam-jackets there must be a combination of two factors: namely difference of temperature between the cylinder and the jacket during the stroke, and time. There must be a difference of temperature, and necessarily therefore a difference

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of pressure between the cylinder and the jacket during part at least of the stroke; and to some extent this condition seemed to have been realised in the experiments; the indicator diagrams might be right or wrong in other respects, but they showed at any rate a difference of pressure, and therefore a difference of temperature, for a good part of the stroke. But the other important factor—time—had been wanting; the pistons were running at 800 to 900 feet per minute, and at those high speeds it did not matter what the expansion and the consequent difference of temperature might be; there was not time for the transference of heat from the jacket to the cylinder to take place. From all the experiments made it appeared to him that the indicator diagrams were not of much use.

The consumption of 26¾ lbs. of steam per I.H.P. per hour he thought was too good a performance under the circumstances, and that it must point to a great deal of priming. In the complete and careful locomotive experiments made by Bauschinger for the Bavarian government thirty years ago, working up hill and down dale, with heavy load and light load, and with goods and passenger trains, the average consumption of steam per I.H.P. per hour came to 27 lbs. In the present experiments the engine had been working under favourable conditions, with a good load and over a good road, and had been carefully looked after in all respects; but of course if the indicator diagrams were wrong, the whole of the conclusions were wrong. That the diagrams were wrong he was quite prepared to believe, from what had been said by Mr. Aspinall (page 484), and from what he had himself seen and known to be the consequence of using small and long pipes to the indicators. On a former occasion (Proceedings 1886, page 364) he had shown some diagrams which proved that, when the indicator was placed direct upon the cylinder, the change had resulted in an increase of no less than 38 per cent. in the area of the indicator diagram obtained. No doubt the same result would have followed in the diagrams now exhibited, if the same change had been made in the way of using the indicators.

Mr. William Schönheyder thought it could hardly have been expected, even before the experiments were made, that any great economy would result from using steam-jackets on locomotive cylinders, because the jacketed surface was far too small for heating the large quantity of steam which passed through the cylinders in so short a time. The measurement of the feed-water he observed had been attempted by means of a water-meter of the inferential kind, which he thought was hardly good enough for such purposes; for many uses it was an excellent meter and sufficiently accurate, but he thought not so for boiler experiments. The tests which had been made of it afterwards were mentioned in page 470 as having given varying results, with a mean error of 2·6 per cent. too low; it would be interesting to know what was the maximum error. Moreover in arranging a water-meter for accurately measuring boiler evaporation, he considered it should never be placed on the suction side of the feed-pump or injector, as had been done in these trials, though it appeared there was a pressure upon the suction side from the tank; but according to the speed of water through the pipe leading from the tender tank to the meter, and the size of the pipe, it was quite possible that, if any leak existed in the pipe or the joints, more or less air might be drawn in, and in that way the registration of the meter might be vitiated. In these experiments it was possible the pipe joints might have been made sound, and might have kept sound; but that was always an untrustworthy way of using a meter. It should always be placed on the pressure or delivery side of the injector or feed-pump: though of course there might not be much room in the locomotive for placing it in that position.

Mr. Henry M. Rounthwaite noticed the absence of any record of the temperature of the external air, or (except in Table 6) of the force or direction of the wind, or whether there was rain falling, or how the weather was in other respects at the time of the trials; these were points which he thought had an important bearing upon the result in the trial of a locomotive. Then again the cylinder with the liner in it, when working without any steam in the space between the liner and the cylinder, was not in the same condition as an ordinary unjacketed cylinder. Including the liner there was thicker metal, not quite twice as thick; and there was the

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air-jacket between. Even if the air were taken to be of no value as a non-conductor, there were two extra surfaces of metal; and in the passage of heat through metals by radiation the great resistance was at the surfaces, in passing from metal to air and again from air to metal. The experiments he therefore thought could not be expected to show the same difference between jacketing and non-jacketing as if in the latter case an ordinary cylinder had been tried without the liner. The arrangement actually tried showed a gain of say 6 or 8 per cent. by jacketing; but, had the liner been absent on the non-jacketed trial, he felt certain this gain would have been nearly double; in that case the comparison would have been between a partly steam-jacketed cylinder and an entirely unjacketed cylinder.

Mr. C. Frewen Jenkin called attention to the feed-water consumption per pound of coal (Table 2, line 25), which varied from 9·31 lbs. to 7·96 lbs., or a variation of 14 per cent., of which no explanation appeared to be offered in the paper. It had been pointed out by Mr. Longridge (page 487) that 12 per cent. might be accounted for by a difference of six inches in estimating the thickness of fuel in the fire-box.

Mr. W. Worby Beaumont asked why the results of the trials were disparaged in page 466 on account of the coal consumption not having been ascertained so accurately as the steam consumption. If the statement in page 466 was correct, that the consumption of steam was obtained with a close approach to absolute accuracy, surely this was the most important point of all in making such experiments. The coal consumption, if it also could have been satisfactorily ascertained, would of course have formed a check upon the results; but surely the steam consumption, if correctly known, ought to be sufficient. With regard to Mr. Aspinall's remark (page 484) as to the errors of indicators, he asked whether it might be supposed that the indicators persisted in the same errors throughout the whole of their indications in these experiments; because it would appear to him that, if they did so, the comparative results would be the same: in other words, if the diagrams were all to the same extent smaller than they ought to be, then the difference between the behaviour of the steam in the cylinders, when the jackets were in use and when they were not, could be just as well ascertained from the indicator diagrams actually obtained as if these had all been as much larger as they ought to have been. This argument of course depended entirely upon whether the same true or false tale was told by the indicators right through the experiments. Doubt had been thrown upon the steam consumption of 26·7 lbs. per I.H.P. per hour; and it would appear that such a doubt would be even greater, if the indicator diagrams were increased in size, as they would be expected to be if connecting pipes of such length as were seen in the drawing were done away with. If the indicator diagrams ought properly to be so much larger, the steam consumption would be reduced to something considerably below the 26·7 lbs. per I.H.P. per hour, affording thereby another illustration of the great economy with which locomotives worked, in contrast with the statements often put forward to prove how much more economical it would be to work locomotives by electricity than by steam. If under its actual conditions of working the engine tried in these experiments would run with a steam consumption of something less than 26·7 lbs. per I.H.P. per hour, it was obvious that electric locomotives would have a great deal to beat. The apparent smallness of the gain due to the jacketing of the cylinders, and also the variation in that small gain, were doubtless explained by the consideration advanced by Mr. Halpin (page 490), namely the high piston-speed. It appeared to himself impossible to expect any gain whatever from the use of a steam-jacket, especially of a jacket having such a thin steam-space, with a piston-speed so high as that in locomotive engines and with the conditions of running so varying. The conditions that obtained in any of the engines which did gain something by jacketing were here entirely absent.

Mr. E. C. de Segundo remarked that, although unfortunately the results of the trials were so indecisive, experience showed how difficult it was to obtain accurate results in experiments of so arduous a nature as these. Even if the trials appeared to some a

(Mr. E. C. de Segundo.)

failure, it would be remembered that the greatest results had often sprung from apparent failures. Having had occasion some time ago to look through the results of a somewhat similar trial, he fully concurred with Mr. Longridge how difficult it was to take accurate indicator diagrams off a locomotive engine. Unless the indicators were placed close to each end of the cylinder, as had been done by Mr. Aspinall (page 484), the diagrams taken could not help being inaccurate. In the diagrams which he had had occasion to examine, taken by the same indicator from both ends of the cylinder, it had been found that those from the back end were three-eighths of an inch longer than those from the front end. The pipe leading to the indicator from the front end was comparatively straight, while that from the back end was brought round a bend to the indicator; and it was discovered that, when the pressure came on the back pipe, the pipe straightened itself on the principle of the Bourdon pressure-gauge, and consequently lengthened the stroke of the indicator, and thereby vitiated the diagram.

Professor T. Hudson Beare had endeavoured to a certain extent to disarm criticism by the statement at the outset of the paper (page 466) that the results were not such as would enable any definite conclusions to be drawn respecting the value of the steam-jacket in locomotives. The great difficulty of carrying out experiments of this kind with an express locomotive had been remarked on by Mr. Aspinall (page 483). It was hard enough to carry out accurate scientific observations on a locomotive going at a low speed; but harder still on an express locomotive travelling at a speed of occasionally sixty miles an hour over a line with large numbers of points and crossings, when the observers had to cling on pretty firmly, in order to avoid being jerked off the foot-plate or the buffer plank. Moreover the apparatus available for these experiments was not everything that could be desired, as had been pointed out in the paper. Although measurement of the feed-water by meter was considered by Mr. Aspinall (page 484) to be on the whole more satisfactory than would have been measurement of the depth of water in the tender, he himself differed entirely from that opinion. All meters had errors; and the worst of a meter was that it could never be known whether the error was the same today as yesterday, and whether it would be the same tomorrow. The meter might be taken off and tested carefully after the trial was over, as had been done in this instance; but there was no certainty that the error so determined was the error which the meter had during the time of the trial. The measurement of the depth of water in the tender he believed was much more reliable than measurement by meter, and it was much more simple. Naturally it could not be expected that the depth in the tender could be measured accurately while the engine was running; but there were certain stoppages in the runs between Manchester and York, which afforded sufficient opportunity for measuring carefully the level of the water in the tender, and so determining the consumption of water during known periods.

In the testing of the meter, the error found was not constant (page 491), but varied between 4 and 1·3 per cent.; the maximum was therefore not much greater than the mean of 2·6 per cent. given in the paper, which was the average of a number of tests.

On the question of the condition of the fires at the beginning and end of each trial, the point intended to be emphasized in the paper was that the real coal consumption could not be known accurately if there were much difference between the amount of incandescent coal on the fire at the end of a run and at the beginning. As pointed out by Mr. Longridge (page 487), it was practically impossible by mere inspection to see how much incandescent fuel there was upon the fire-bars of a locomotive. On a journey of less than two hours, where the total consumption of coal was not more than about one ton, an error in estimating the allowance to be made for such variation in the fuel on the fire-bars would make a serious difference in the result. If there was a thick fire at the end and only a thin fire at the start, or conversely, the proportionate error would be great. It was on this account that he thought it would have been more satisfactory in such a trial if the fire could have been worked down to the same thickness at the end as it had at the beginning. Although it had not been

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practicable in this instance, that was what should be aimed at in boiler trials, so as to eliminate error arising from estimating the condition of the fire.

With regard to a counter, he was still disposed to reiterate what had been said in the paper, that a counter would have been much more satisfactory than any speed recorder. Counters gave positive direct results; but any recorder had errors, which had to be allowed for and corrected. It was objectionable he considered in any experiments to have observations which had afterwards to be corrected for errors of instruments. Some degree of error attached of course to every instrument; but if an instrument could be used with an error which might be neglected, so much the better.

Possibly the difficulty of estimating the condition of the fire at the beginning and end of a run, and therefore of determining accurately the coal measurement, affected considerably the evaporation per pound of coal as given in the tables; and therefore, although the latter appeared so high, it might not be due mainly to priming, as had been suggested by Mr. Longridge (page 488), though there might perhaps be some priming; but it might be due in part to the above causes. There had been a great deal of trouble with the indicators, owing, as had been pointed out by Mr. Aspinall (page 484), to the water in the pipes; of this it had been endeavoured to get rid as much as possible by blowing through just before taking each diagram. The consequent errors in the indicators he imagined had not been large, and had probably been about the same in each trial, so that it was considered comparative figures would not be vitiated thereby; for this reason no attempt had been made to calibrate their errors. The trials, after all, were comparative; and any errors in the indicators would hardly be likely to vary much during the two days' consecutive trials.

With regard to the high evaporation of locomotive boilers, he thought Mr. Halpin's remarks (page 489) undoubtedly furnished a good explanation: namely that a locomotive boiler was in a continual state of vibration, which must greatly facilitate the liberation of the globules of steam as fast as they were formed, and their escape to the surface of the water, thereby greatly helping the transmission of heat through the tubes and the plates. Every one who had experimented on heat transmission through plates knew that, if the steam globules were got rid of as fast as they were formed, the heat went through with great rapidity indeed.

The only explanation he could offer of the variation in the feed-water evaporation per pound of coal (page 492) was that given in page 466, namely the difficulty of determining the quantity of fuel on the fire at the beginning and at the end of each experiment. None of the observations of the consumption of water were incorrect beyond the extent of the meter error; and undoubtedly, after correction for that error, the quantities of water recorded in Table 2 did really go into the boiler. Whether all came out as steam, or whether it came out partly as steam and partly as priming water, there were no means of saying; but in the total consumption he believed there was no error. With regard to the fuel, while he was certain that the actual quantity which was put upon the fires was weighed and recorded carefully, the admitted error arose from the doubt about the condition of the fire at the beginning and at the end. If these several points were taken into account, he thought it would still be found that these results were of some use, even though they did not throw any definite light upon the important question whether the steam-jacket was or was not of advantage in a locomotive engine.

The information asked for about the weather at the time of the trials (page 491) had now been inserted in lines 5–7 of Table 3. It might be of interest to add that the amount of coal burnt in lighting up in the running shed at Horwich was 400 lbs. on 18th September, and 600 lbs. was used in getting up steam to 160 lbs. pressure and coming to Manchester; and 289 lbs. was burnt while standing in the station yard at York. On 19th September 800 lbs. was used in getting up steam and coming to Manchester from the running shed; the amount burnt while standing in the yard at York was not noted.

Mr. Bryan Donkin, Member of Council, recalled that the whole of the special arrangements connected with the locomotive, and also

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the whole of the experimental appliances, had been provided by the kindness of Mr. Aspinall; and all that the observers had to do was to take the utmost possible advantage of them for making the trials. Their thanks therefore ought to be particularly accorded to Mr. Aspinall for the kind way in which he had put this express locomotive at their disposal, and fitted it so extensively with testing apparatus. If he ever adopted a compound locomotive, he hoped he would give them an opportunity of making another trial. Here it had been a single-cylinder engine; but in a compound engine, having an efficient steam-jacket on the low-pressure cylinder and covers, a much greater head of heat would be obtained, and the advantages of steam-jacketing he considered would tell much more in the low-pressure cylinder than in the high, as had been proved by many experiments on stationary engines. As shown in Table 1, the proportion of internal surface exposed to the steam-jackets in the clearance space was here only a little more than one quarter of the total internal clearance surface; and at 90 per cent. of the stroke the internal jacketed surface was only a little more than half of the total internal clearance and cylinder surface. This was in his opinion the key to the whole question. Some interesting experiments, bearing upon steam-jackets for locomotives, had lately been made in France on the Paris and Orleans Railway. There were two locomotives, exactly similar in every other respect including boilers, and twenty-four experiments were made with each: one engine had four Corliss valves to each cylinder, and in the other there were the usual slide-valves. There was a gain of about 12 per cent. economy in water consumption in favour of the locomotive with Corliss valves. This he considered was partly due to the ends of the cylinders being practically jacketed with live steam on the boiler side of the Corliss valves; and partly to diminished initial condensation, because with four Corliss valves to each cylinder the steam had not to go through the same ports: the live steam entered through two ports, and the exhaust steam passed out through two other ports; and thereby the condensation in the cylinder and passages was considerably reduced. Actually there were not any steam-jackets; but the mere fact of the two Corliss valves being put on the top at each end was equivalent to jacketing the cylinder ends, which were the most important surfaces.

That there must have been priming, he agreed with Professor Beare and Mr. Longridge; but to what extent it was difficult to say. In some experiments made on the Great Eastern Railway nine years ago by Professor Kennedy and himself* they had been troubled in the same way with priming, and the heat account had overbalanced.

The large amount of evaporation by a locomotive boiler had been confirmed by those Great Eastern Railway experiments, in which the water had been actually measured in the tender. Though the locomotive boiler was so excellent an evaporator, it primed; and it primed in the shops just as badly as on the road, because it had been found that the evaporation was about the same in the locomotive on the Great Eastern Railway, both in the shop and on the road, causing the heat account to overbalance in each instance. As in many stationary boilers, the priming was not got rid of, even when the locomotive was standing still.

To measure the water in the tender he agreed with Professor Beare would have been the best plan, and to trust to no meter, however accurate it might be. It would have been easy with a float to read off the depth of water when the locomotive was standing on the level; the tender might either be filled by gauge cans, or might be weighed. It had actually been weighed at the beginning and at the end of each run in the Great Eastern Railway tests.

Jacketing locomotive cylinders by drawing the hot smoke-box gases round them, as had been tried by Mr. Aspinall (page 485), had been tested also in Italy, he believed with considerable success. Some experiments had been published by Mr. Kossuth, who seemed to have proved that there was some economy.

The indicator pipes had been well covered, and it seemed to him that if there were any errors in the indicator diagrams, arising from water in the pipes, they would be the same throughout the trials, and would not affect the comparison of jacketing and non-jacketing. The high piston-speed was a much more important point.

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* See "Engineering," 21 October 1892, pages 501–4.

The President thought it must be a gratification to the authors that the paper had elicited such a discussion, because it showed how interesting it had been, and how valuable in one way or another were the results. Not that much economy had as yet been shown, because the experiments had been conducted under unfavourable conditions, upon a run much too short to prove the value of the steam-jacket. No doubt what a locomotive superintendent looked to was the saving of coal. On the Midland Railway Mr. Johnson had a long run of about 200 miles, he believed, with few stoppages; and if he would fit up a locomotive either with steam-jacketed cylinders or with a superheater, he was sure that, as the present paper had been received by the members with so much satisfaction, the same observers would be induced again to venture to carry out some further experiments. With the experience they had already obtained, they would probably be able to bring results before the Institution which would be highly valuable and interesting. The present experiments had been conducted under most difficult conditions; and he had great pleasure in proposing a hearty vote of thanks to Professor Beare and Mr. Donkin for their interesting communication, and to Mr. Longridge for his cc-operation in the trials; and also to Mr. Aspinall, by whom they were originally suggested, for his kindness in fitting up the locomotive and making all the necessary arrangements for carrying out the experiments.

TRANSMISSION OF HEAT FROM SURFACE CONDENSATION THROUGH METAL CYLINDERS.

By Lt.-Colonel ENGLISH and Mr. BRYAN DONKIN.

There are many conflicting opinions as to the rate at which heat, liberated by the surface condensation of steam, is transmitted through a metallic wall, such as a steam-jacketed cylinder or a condenser tube; and the authors believe that the results of a series of trials, designed to clear up some doubtful points in previous experiments, will be of interest. So far as they are aware, no previous attempts have been made to ascertain the actual temperatures in the interior of the metal, or to observe the exact appearance of the film of water deposited, or to determine whether such a phenomenon as cloudy steam really exists. These, and other questions involved in equal obscurity, can readily be answered by the help of the apparatus they have used, which consists of a strong vertical glass cylinder, about $5\frac{3}{8}$ inches diameter and $2\frac{3}{4}$ inches high, filled with steam, and enclosing a metallic cylinder, through the interior of which an ascending stream of cooling water is made to circulate. In order to determine the thermal gradients in the metal, when its thickness allowed of so doing, the temperatures of the interior were taken in vertical holes 1–8th or 1–16th inch diameter, drilled at different distances from the condensing surface, and filled with mercury, into which slender thermometers were inserted.

The general arrangement of the apparatus is represented in Figs. 1 and 5, Plate 116, in which one of the experimental metal cylinders A is shown in vertical section, secured by external bolts between cast-iron top and bottom covers, the joints being formed with flat india-rubber rings. Outside the metal cylinder A and concentric with it, the glass cylinder D of the same length was held in a similar manner between the same covers. Steam of any pressure, up to 30 lbs. per square inch above atmosphere, can be safely introduced into the annular space C, between D and A, by means of a steam pipe passing through the top cover. This steam pipe is furnished with a pressure gauge; and a thermometer, whose stem passes through a gland in the top cover, has its bulb immersed in the steam. In order to obtain a complete and regular circulation of cooling water up through the metal cylinder A, a small reservoir is fixed at F, and is kept filled with water at approximately the same temperature as that of the room. By opening a cock E, the water is allowed to flow into the pipes GH, and thence upwards through the interior of the cylinder A, passing away by the discharge pipe I at top. The quantity of circulating water can be varied by adjusting the cock J on the pipe G, the same head being always maintained in the upper part of this pipe, which is formed of a glass tube. At I the discharged water runs down a funnel L into a reservoir K, from which it can be weighed. Two thermometers at M and N serve to determine the temperature of the circulating water, before and after passing through the apparatus. All the water is brought into close contact with the interior surface of the metal cylinder A by means of a circular plug B, which leaves only a small annular passage for the upward flow of circulating water. The water resulting from condensation on the interior of the glass cylinder D is kept separate from that formed on the outside of the metal cylinder A, by means of an annular rib projecting upwards from the bottom cover. These two quantities of water as they accumulate are drawn off by two cocks projecting downwards from the bottom cover, and are separately collected for weighing. In Plates 116 to 118 are given in plan and vertical section the details of the various metal cylinders which were tried, drawn one-third full size.

From careful observations made in all the trials, the authors consider that it was not possible to trace the slightest appearance of cloudiness or mist, or of water suspended in the body of the condensing steam. In Fig. 19, Plate 119, is given a representation, from a photograph, of the film of water on the surface of smooth cast-iron, as it appeared through the glass cylinder, with a steam pressure of 20 lbs. per square inch and at a somewhat slow rate of condensation.

No drops appeared to exceed about one-fifth of an inch diameter; and after any drop had run down the wall, its path appeared dry. The formation of a network of particles or globules of water, too small at first to be separately distinguished, was next seen covering the same path. These gradually increased in size to about one-hundredth of an inch diameter, when they ran together, coalescing in irregular shapes until they ran down the wall, or were dragged down by larger drops.

The principal object of the trials was to determine the rate at which heat, derived from the condensation of steam at several uniform temperatures, could be transmitted through the wall of each metallic cylinder, under varying conditions. The results are plotted in the series of curves shown in Fig. 20, Plate 120. The velocity of the circulating water vertically upwards over the inner surface of the cylinder was varied between 0·032 and 0·415 foot per second, as shown by the abscissæ or horizontal dimensions. The ordinates show the heat transmitted per second per square foot of external surface of the metallic wall. The different metallic cylinders which were tried include cast-iron with both rough and smooth surfaces, 11–32nds and 31–32nds of an inch thick, copper and brass with smooth surfaces 2–32nds of an inch thick, and smooth steel 1–32nd and 10–32nds of an inch thick.

There are two separate and independent ways of measuring the rate of heat transmission :—one by observing the rise of temperature in a known quantity of circulating water; and the other by observing the weight of steam condensed. Both these methods however require a correction for the amount of heat transmitted to the circulating water by conduction through the top and bottom metal covers. The amount of this correction was determined by removing the metal cylinder, and substituting a glass cylinder of the same external diameter, Figs. 2 and 3, Plate 116; within this inner glass cylinder was enclosed a central metal pipe, through which the circulating water flowed upwards; and an annular air-space was left between this pipe and the inner glass cylinder. By this means practically all the heat which was transmitted from the steam to the circulating water had to pass through the covers under the same conditions as in the trials. This heat could be measured by the rise in temperature of the circulating water, with different steam temperatures; and the necessary deduction for the number of thermal units transmitted through the covers at any temperature could be readily ascertained.

The method of calculating the heat transmission from the weight of steam condensed requires a further correction for external radiation from the glass cylinder and from the covers. This was determined at various steam temperatures by weighing the steam condensed in a given time when no circulating water was passing through the apparatus, whilst the external temperature of the room was kept approximately the same as in the trials, namely about 80° Fahr.

The experiments were divided into nine series, in each of which some variation was made in the material, condition of surface, or thickness of the metallic cylinder wall; and each series comprised several variations of the steam temperature or of the quantity of circulating water. In each trial observations were not commenced until conditions of uniform temperature had been well established; after which the steam temperature, the temperatures in the interior of the metal, and the initial and final temperatures of the circulating water were noted every three minutes. At the end of fifteen minutes the trial was stopped, the quantity of condensed steam which had accumulated was measured, and the circulating water which had passed through the apparatus was weighed. Each trial was made in duplicate, and when necessary was further repeated until an agreement was obtained. The greatest quantity of heat transmitted per second was about 35 thermal units and the least about 7 thermal units per square foot of internal surface of cylinder.

The cast-iron cylinders were of good hard cylinder metal, cast in Messrs. Bryan Donkin and Co.'s foundry. The copper and brass were ordinary commercial tubing; and the steel cylinders were of cold-drawn metal, kindly presented by the Credenda Company of Sheffield.

In the authors' opinion the results of their experiments show that the film of water deposited by condensation and adherent to a metallic surface resists the transmission of heat in exactly the same way as an equivalent greater thickness of metal would do: so that the difference of temperature between the steam and the actual outer surface of the metal will depend upon the mean thickness of the water film and upon the rate of flow of heat through it. The thickness of the water film, as determined from the difference of temperatures, is decidedly less on a smooth surface of cast-iron than on a rough one, and is apparently not affected by the admission of steam in jets to sweep the surface, as in Figs. 8 and 9, Plate 117. There is no apparent difference, in the resistance to transmission of heat, between the surface layer of metal and that next to it; or, in other words, there is no drop in temperature on entering or leaving the metal, as shown in Fig. 18, Plate 119. The thermal gradient at any point in the metal would be uniform in a flat plate, and becomes steeper towards the interior of a hollow cylinder as the circumference diminishes, as in Fig. 18. At any point on the surface of the metal next to the circulating water, the temperature, owing to an adherent film in which a thermal gradient exists, is much in excess of the mean temperature of the circulating water at the same point. The rate of condensation or flow of heat increases, but in a constantly diminishing ratio, with the difference between the temperature of the steam and that of the circulating water at the point considered, and with the velocity of the circulating water, as shown by the curves in Plate 120.

APPENDIX.

In Table 1 (pages 510–521) are given the detailed results of observations made during the series of trials 1 to 6, in which the cylinders were sufficiently thick to allow of ascertaining the temperature of the metal at points in its interior; and also in the series 7 to 9, in which the thickness of metal was too small to allow of ascertaining the temperatures in its interior. In this table at the head of each series are given the material and thickness of the metal cylinder, and the condition of its surfaces; the nature of the steam admission; the radii of the outside and inside surfaces; the effective areas outside and inside the cylinder, with their ratio N; the radii of the cylinder at the points where the thermometers were inserted; the quantity of heat conducted to the water through the covers, and also the radiation, in thermal units per second per square foot of outside surface. The above ratio N is also the coefficient by which the number of thermal units per square foot of outside surface must be multiplied, in order to give the corresponding thermal units transmitted per square foot of inside surface.

Line 10 gives the temperature in the interior of the wall, shown by the thermometer in the outer hole; line 11 in the middle hole; and line 12 in the inner hole. Line 13 shows the observed initial temperature of the circulating water; and line 14 its observed final temperature, corrected for the rise of temperature due to the conduction of heat through the covers. Line 16 gives the velocity of the circulating water in feet per second; line 17 the total observed weight of circulating water in lbs. per minute; and line 18 the weight of circulating water in lbs. per second per square foot of inside surface. Line 22 gives the observed temperature of the steam. Line 23 gives the total observed weight of the condensed steam collected from the walls in lbs. per minute. Line 24 gives the observed weight of circulating water per second per square foot of external surface, multiplied by its rise in temperature; so that, if H is the number of thermal units transmitted per second per square foot of external surface of cylinder, and C the number of thermal units transmitted per second per square foot of external surface to the circulating water through the covers, $H + C$ will be represented by the quantities given in this line. Line 25 gives the observed weight of condensed steam collected from the vertical walls per second per square foot of external surface, multiplied by its latent heat per lb.; so that, if R is the number of thermal units lost by external radiation per second per square foot of external surface, $H + C + R$ will be represented by the quantities given in this line. Line 26 gives the number of thermal units transmitted per second per square foot of internal surface, as obtained by multiplying the value of $\{(H + C) - C\}$ by the coefficient N. Line 27 gives the number of thermal units transmitted per second per square foot of internal surface, as obtained by multiplying the value of $\{(H + C + R) - (C + R)\}$ by the coefficient N. Line 28 gives the calculated thickness z of the film of condensed steam deposited on the metallic surface, as arrived at by the formula given in page 509.

Previous Experiments.—There are not many published experiments on the transmission of heat from surface condensation through metallic cylinders; but the following are sufficiently in detail for enabling a comparison to be made with the authors' results.

(1) Mr. B. G. Nichol of the Ouseburn Engine Works, Newcastle-on-Tyne, made a series of trials on brass tubes in 1875, of which the results are recapitulated in the Proceedings of this Institution 1894, pages 158–9. [See Table 2, page 522; and Fig. 22, Plate 121.]

(2) Mr. G. A. Hagemann of Copenhagen made a set of experiments, about 120 in number, described in the Proceedings of the Institution of Civil Engineers, 1884, vol. lxxvii, pages 311–22. These experiments were made with a vertical brass tube $1\frac{15}{16}$ inch external diameter, 3–32nds inch thick, and 37 inches long, placed centrally inside a cast-iron tube of 6 inches bore; cooling water flowed upwards through the brass tube, while steam was condensed in the annular space. The steam was of various temperatures from 190° to 280° Fahr., and the temperature and velocity of the circulating water were also varied between wide limits. [See Table 3, pages 522–525; and Fig. 23, Plate 121.]

The observed results of Nichol's, Hagemann's, and the authors' experiments, which are plotted as curves in Plate 121, can be represented closely by the formula

$$F = \sqrt{t_b - t}\,(A\sqrt{v} + B\sqrt{t_b - 212^\circ})$$

where F is the flow of heat at any point in the tube in thermal units per square foot of internal surface per second (Table 1, lines 26-7), v the velocity of the circulating water in feet per second (Table 1, line 16), t_b the temperature of the steam in degrees Fahrenheit, t the mean temperature to which the circulating water has been raised at the point considered in the tube; and A and B are constants depending upon the nature of material, thickness, length, and diameter of the tube with which the experiments were made.

The final temperature t_c of the circulating water (Table 1, line 15) can be obtained from this formula by means of the following equations, in which

F_i is the flow of heat per square foot per second at the inlet,
F_f „ „ „ „ „ „ „ outlet,
t_i the initial temperature of the circulating water (line 13),
c the weight in pounds of circulating water passing over each square foot of metallic surface per second (Table 1, line 18), so that the ratio $c \div v$ is constant for the same tube:—

$$F_i = \sqrt{t_b - t_i}\,(A\,\sqrt{v} + B\,\sqrt{t_b - 212^\circ})$$

$$F_f = \sqrt{t_b - t_c}\,(A\,\sqrt{v} + B\,\sqrt{t_b - 212^\circ})$$

$$\frac{F_i + 2F_f}{3} = c\,(t_c - t_i)$$

In line 15 of Table 1 and in Tables 2 and 3 are given the resulting values of t_c according to these equations, for the experiments referred to, with the following constants:—

		Thickness.	Ratio.	Constants.	
		Inch.	$c \div v$	A	B
Nichol, brass tube, vertical		0·049	0·138	0·40	0·120
„ „ „ horizontal		„	„	0·55	0·165
Hagemann, brass tube		0·094	0·196	0·80	0·096
English and Donkin	cast-iron, rough	0·345	2·65	1·67	0·038
	„ smooth				
	„ „ with jets				
	„ rough „ „				
	„ smooth	0·980	1·70	1·33	0·037
	steel, smooth	0·320	3·28	2·50	0·067
	„ „	0·030	3·52	2·00	0·270
	copper „	0·062	„	4·50	0·270
	brass „	0·070	„	3·50	0·210

In those of the authors' experiments in which thermometer readings were obtained of the temperatures in the interior of the metal, the mean thickness z of the film of water deposited by condensation on the outer surface of the tube can be deduced from any one of these readings t_t at the radius r_t by the formula

$$800z = \frac{t_b - t_t}{F} - 8r_b \log_\epsilon \frac{r_b}{r_t}$$

and these are the values shown in Table 1, line 28, as deduced from the observed temperature by the thermometer nearest the middle of the thickness of metal.

The temperature t_y of the inner surface of the metal can be obtained either by using the ascertained value of z in the formula

$$t_b - t_y = (8r_b \; log_\epsilon N + 800z) \times c \frac{(t_c - t_i)}{N}$$

or by a calculation independently of z according to the formula

$$m \; (t_b - t_z) = t_z - t_y = 8r_b \log_\epsilon N \times c \frac{(t_c - t_i)}{N}$$

t_z being the temperature of the outer surface of the metal, and m a constant for each cylinder of the following value:—

For cast-iron, rough . . .	0·345 inch thick,	constant $m =$	1·0
„ „ „ smooth . . .	0·345 „ „	„ „	2·0
„ „ „ „ . . .	0·980 „ „	„ „	10·0
„ steel „ . . .	0·320 „ „	„ „	1·4

The values of t_y calculated in these two different ways are given for comparison in lines 20 and 21 of Table 1.

The values of t_z the temperature of the outer surface of the metal, as deduced from those of t_y, are given in line 19 of Table 1.

TABLE 1 (*continued to page 521*).—*Transmission of Heat from Surface Condensation through Metal Cylinders.*

		Series 1. *See Figs. 4 and 5, Plate* 116.					Series 2. *See Figs. 6 and 7, Plate* 117.				
1	Material and Thickness of Cylinder	Cast-Iron, 31–32nds inch thick.					Cast-Iron, 11–32nds inch thick.				
2	Condition of surfaces	Smooth both sides.					Smooth both sides.				
3	Nature of steam admission	In one jet.					In one jet.				
4	Radii, outside and inside	1·50 and 0·52 inch.					1·50 and 1·16 inch.				
5	Effective Areas, outside and inside	0·182 and 0·062 square foot.					0·182 and 0·140 square foot.				
6	Ratio of outside area to inside . *N*	2·90 to 1·00					1·30 to 1·00				
7	Radii at thermometers	1·13 and 0·99 and 0·72 inch.					1·47 and 1·39 and 1·31 inch.				
8	Heat per second per square foot of external surface: Conduction through covers *C*	0·3 thermal unit.					0·3 thermal unit.				
9	Radiation . *R*	1·3 thermal unit.					1·3 thermal unit.				
	Number of trial . . . . No.	206	208	209	210	207	174	176	177	179	175
10	Temperature of Wall: outer thermometer Fahr.	227°	218°	215°	215°	212°	—	—	—	—	—
11	middle ,, Fahr.	220°	209°	205°	204°	202°	214°	207°	202°	200°	200°
12	inner ,, Fahr.	211°	192°	188°	185°	178°	212°	201°	196°	192°	190°
13	Temperature of Circulating Water: initial . . Fahr.	88·6°	75·0°	77·6°	75·2°	75·9°	80·0°	76·9°	78·1°	74·5°	81·3°
14	final, observed Fahr.	125·9°	96·6°	93·6°	87·6°	83·7°	131·9°	112·2°	105·8°	95·4°	96·7°
15	,, calculated Fahr.	123°	94°	93°	88°	84°	136°	105°	101°	92°	97°

TABLE 1 (*continued from opposite page*).

			Series 1.					Series 2.				
	Number of trial	No.	206	208	209	210	207	174	176	177	179	175
16	Circulating Water, Velocity	feet per sec.	0·124	0·347	0·521	0·741	1·438	0·032	0·123	0·169	0·256	0·377
17	Circulating Water, Weight per minute	lbs.	0·79	2·20	3·31	4·72	9·13	0·71	2·75	3·76	5·74	8·45
18	Circulating Water, ,, per sec. per sq. ft. of inside surface	lbs.	0·21	0·59	0·89	1·27	2·46	0·08	0·33	0·45	0·68	1·00
19	Temperature calculated, Outer surface	Fahr.	231°	229°	228°	228°	225°	222°	220°	220°	216°	212°
20	Temperature calculated, Inner ,,	Fahr.	199°	179°	167°	156°	138°	210°	198°	195°	187°	176°
21	Temperature calculated, Inner ,,	Fahr.	200°	178°	165°	155°	142°	207°	194°	188°	183°	171°
22	Steam, Temperature	Fahr.	234°	234°	234°	235°	234°	228°	231°	232°	230°	231°
23	,, Weight condensed per minute	lb.	0·015	0·061	0·066	0·071	0·078	0·071	0·110	0·117	0·133	0·140
	TOTAL HEAT *per second per square foot of* External *surface.*											
24	From circulating water, $H+C$	Th. U.	2·7	4·4	4·8	5·5	6·6	3·7	8·9	9·5	11·0	11·9
25	From steam condensed, $H+C+R$,	Th. U.	3·9	5·3	5·7	6·1	6·8	6·2	9·6	10·2	11·6	12·2
	NET HEAT *per second per square foot of* Internal *surface.*											
26	From circulating water, $\{(H+C)-C\}\times N$	Th. U.	7·0	11·9	13·0	15·1	18·2	4·4	11·2	11·9	13·9	15·0
27	From steam condensed, $\{(H+C+R)-(C+R)\}\times N$	Th. U.	6·7	10·7	11·9	13·0	15·1	6·0	10·4	11·2	13·0	13·8
28	Estimated Thickness of film of condensed steam deposited	inch	0·0012	0·0018	0·0022	0·0018	0·0007	0·0032	0·0025	0·0030	0·0025	0·0023

TABLE 1 (*continued from preceding page*).

Transmission of Heat from Surface Condensation through Metal Cylinders.

				Series 3. *See Figs. 8 and 9, Plate* 117.					Series 4. *See Figs. 6 and 7, Plate* 117.				
1	Material and Thickness of Cylinder			Cast-Iron, 11–32nds inch thick.					Cast-Iron, 11–32nds inch thick.				
2	Condition of surfaces			Smooth both sides.					Rough both sides.				
3	Nature of steam admission			In twenty-five jets.					In one jet.				
4	Radii, outside and inside			1·50 and 1·16 inch.					1·50 and 1·16 inch.				
5	Effective Areas, outside and inside			0·182 and 0·140 square foot.					0·182 and 0·140 square foot.				
6	Ratio of outside area to inside		*N*	1·30 to 1·00					1·30 to 1·00				
7	Radii at thermometers			1·47 and 1·39 and 1·31 inch.					1·47 and 1·39 and 1·31 inch.				
8	Heat per second per square foot of external surface	Conduction through covers	*C*	0·3 thermal unit.					0·3 thermal unit.				
9		Radiation	*R*	1·3 thermal unit.					1·3 thermal unit.				
	Number of trial		No.	184	181	180	182	183	169	167	166	164	168
11	Temperature of Wall	middle thermom.	Fahr.	212°	205°	206°	198°	192°	209°	195°	194°	190°	187°
12		inner ,,	Fahr.	209°	201°	201°	192°	186°	207°	190°	190°	185°	180°
13	Temperature of Circulating Water	initial	Fahr.	75·5°	78·1°	82·5°	77·0°	70·7°	79·4°	86·7°	90·4°	83·9°	77·2°
14		final, observed	Fahr.	138·1°	125·4°	108·6°	97·6°	84·4°	121·7°	117·7°	117·0°	102·9°	91·0°
15		,, calculated	Fahr.	132°	118°	106°	95°	84°	130°	112°	111°	99°	91°

TABLE 1 (*continued from opposite page*).

		Series 3.					Series 4.				
	Number of trial . . . No.	184	181	180	182	183	169	167	166	164	168
16	Circulating Water: Velocity . . . feet per sec.	0·035	0·062	0·157	0·242	0·415	0·041	0·128	0·173	0·271	0·409
17	Circulating Water: Weight per minute . . lbs.	0·79	1·40	3·52	5·43	9·29	0·93	2·87	3·88	6·07	9·17
18	Circulating Water: ,, per sec. per sq. ft. of inside surface lb.	0·09	0·17	0·42	0·65	1·10	0·11	0·34	0·46	0·72	1·09
19	Temperature calculated: Outer surface Fahr.	224°	222°	219°	216°	210°	219°	212°	209°	204°	195°
20	Temperature calculated: Inner . Fahr.	211°	206°	195°	188°	174°	205°	191°	186°	178°	158°
21	Temperature calculated: Inner ,, Fahr.	207°	203°	194°	186°	172°	199°	186°	184°	179°	158°
22	Steam, Temperature . . . Fahr.	232°	230°	231°	230°	228°	233°	233°	232°	230°	232°
23	,, Weight condensed per minute . . lb.	0·081	0·105	0·108	0·127	0·140	0·077	0·105	0·117	—	0·139
	TOTAL HEAT *per second per square foot of* External *surface.*										
24	From circulating water, $H+C$ Th. U.	5·4	7·2	10·0	12·2	13·8	3·6	8·1	9·4	10·6	11·6
25	From steam condensed, $H+C+R$, Th. U.	8·3	10·8	11·1	13·1	14·5	6·7	9·1	10·2	—	12·1
	NET HEAT *per second per square foot of* Internal *surface.*										
26	From circulating water, $\{(H+C)-C\}\times N$ Th. U.	6·6	9·0	12·6	15·5	17·5	4·3	10·2	11·8	13·4	14·7
27	From steam condensed, $\{(H+C+R)-(C+R)\}\times N$ Th. U.	8·7	12·0	12·4	15·0	16·8	6·6	9·8	11·2	—	13·6
28	Estimated Thickness of film of condensed steam deposited inch	0·0033	0·0028	0·0022	0·0023	0·0023	0·0060	0·0050	0·0041	0·0037	0·0040

TABLE 1 (*continued from preceding page*).

Transmission of Heat from Surface Condensation through Metal Cylinders.

		Series 5. *See Figs. 8 and 9, Plate 117.*				Series 9. *See Figs. 16 and 17, Plate 118.*					
1	Material and Thickness of Cylinder .	Cast-Iron, 11–32nds inch thick.				Brass, 2–32nds inch thick.					
2	Condition of surfaces	Rough both sides.				Smooth both sides.					
3	Nature of steam admission . . .	In twenty-five jets.				In one jet.					
4	Radii, outside and inside . . .	1·50 and 1·16 inch.				1·50 and 1·43 inch.					
5	Effective Areas, outside and inside .	0·182 and 0·140 square foot.				0·182 and 0·175 square foot.					
6	Ratio of outside area to inside . *N*	1·30 to 1·00				1·01 to 1·00					
7	Radii at thermometers . . .	1·47 and 1·39 and 1·31 inch.				No holes in cylinder.					
8	Heat per second per square foot of external surface: Conduction through covers *C*	0·3 thermal unit.				0·3 thermal unit.					
9	Heat per second per square foot of external surface: Radiation . *R*	1·3 thermal unit.				1·3 thermal unit.					
	Number of trial . . . No.	185	186	187	188	217	218	219	220	221	222
11	Temperature of Wall, middle thermom. Fahr.	203°	193°	184°	178°						
12	Temperature of Wall, inner ,, Fahr.	200°	189°	177°	171°						
13	Temperature of Circulating Water, initial . . Fahr.	84·5°	82·5°	72·4°	69·1°	81·5°	79·0°	72·2°	70·1°	70·1°	72·7°
14	Temperature of Circulating Water, final, observed Fahr.	133·3°	108·6°	91·6°	83·1°	189·1°	142·4°	110·2°	96·5°	98·4°	126·7°
15	Temperature of Circulating Water, ,, calculated Fahr.	132°	106°	90°	83°	175°	137°	108°	101°	105°	128°

TABLE 1 (*continued from opposite page*).

		Series 5.				Series 9.					
	Number of trial . . . No.	185	186	187	188	217	218	219	220	221	222
16	Circulating Water: Velocity . . . feet per sec.	0·043	0·158	0·266	0·407	0·055	0·118	0·216	0·307	0·323	0·158
17	Circulating Water: Weight per minute . . lbs.	0·96	3·54	5·97	9·10	1·63	3·49	6·30	9·07	9·51	4·65
18	Circulating Water: ,, per sec. per. sq. ft. of inside surface lb.	0·11	0·42	0·71	1·08	0·16	0·34	0·62	0·88	0·93	0·45
19	Temperature calculated: Outer surface Fahr.	217°	205°	197°	191°						
20	Temperature calculated: Inner ,, Fahr.	204°	181°	167°	155°						
21	Temperature calculated: Inner ,, Fahr.	201°	182°	170°	158°						
22	Steam, Temperature . . Fahr.	230°	229°	227°	227°	228°	222°	218°	217°	232°	232°
23	,, Weight condensed per minute . . lb.	0·079	0·105	0·127	0·140	0·191	0·237	0·259	0·274	0·298	0·255
	TOTAL HEAT *per second per square foot of* External *surface.*										
24	From circulating water, $H+C$ Th. U.	5·1	10·0	12·5	13·9	16·0	20·2	22·2	21·9	24·7	23·0
25	From steam condensed, $H+C+R$, Th. U.	8·2	10·9	13·1	14·5	16·7	20·8	22·9	24·1	26·0	22·2
	NET HEAT *per second per square foot of* Internal *surface.*										
26	From circulating water, $\{(H+C)-C\}\times N$ Th. U.	6·2	12·6	15·9	17·7	16·3	20·7	22·8	22·5	25·4	23·7
27	From steam condensed, $\{(H+C+R)-(C+R)\}\times N$ Th. U.	8·6	12·1	15·0	16·8	15·7	20·0	22·2	23·4	25·4	21·5
28	Estimated Thickness of film of condensed steam deposited inch	0·0050	0·0037	0·0035	0·0036						

TABLE 1 (*continued from preceding page*).

Transmission of Heat from Surface Condensation through Metal Cylinders.

			Series 6. *See Figs.* 10 *and* 11, *Plate* 117.							
1	Material and Thickness of Cylinder		Steel, 10–32nds inch thick.							
2	Condition of surfaces		Smooth both sides.							
3	Nature of steam admission		In one jet.							
4	Radii, outside and inside		1·50 and 1·19 inch.							
5	Effective Areas, outside and inside		0·182 and 0·144 square foot.							
6	Ratio of outside area to inside	*N*	1·26 to 1·00							
7	Radius at thermometer		1·43 inch.							
8	Heat per second per square foot of external surface: Conduction through covers	*C*	0·3 thermal unit.				0·9 thermal unit.			
9	Heat per second per square foot of external surface: Radiation	*R*	1·3 thermal unit.				1·5 thermal unit.			
	Number of trial	No.	197	198	199	200	201	202	203	204
11	Temperature of Wall by thermometer	Fahr.	221°	218°	200°	195°	238°	232°	223°	224°
13	Temperature of Circulating Water: initial	Fahr.	80·0°	85·7°	73·9°	69·9°	87·5°	85·2°	74·4°	71·4°
14	Temperature of Circulating Water: final, observed	Fahr.	152·2°	120·4°	101·4°	89·0°	183·9°	136·7°	109·2°	95·3°
15	Temperature of Circulating Water: " calculated	Fahr.	150°	118°	99°	88°	169°	134°	114°	95°

TABLE 1 (*continued from opposite page*).

						Series 6.			
	Number of trial . . . . No.	197	198	199	200	201	202	203	204
16	Circulating Water, Velocity . . . . . . foot per sec.	0·034	0·121	0·202	0·314	0·050	0·119	0·205	0·319
17	Circulating Water, Weight per minute . . . . lbs.	0·97	3·43	5·75	8·90	1·42	3·37	5·81	9·05
18	Circulating Water, " per sec. per sq. ft. of inside surface . . lb.	0·11	0·40	0·67	1·03	0·16	0·39	0·69	1·04
19	Temperature calculated, Outer surface . . . Fahr.	221°	211°	203°	201°	251°	242°	232°	231°
20	Temperature calculated, Inner " . . . Fahr.	204°	183°	166°	160°	222°	200°	177°	174°
21	Temperature calculated, Inner " . . . Fahr.	213°	196°	171°	162°	217°	199°	168°	172°
22	Steam, Temperature . . . . Fahr.	233°	231°	229°	230°	271°	272°	270°	270°
23	" Weight condensed per minute . lb.	—	0·125	0·161	0·175	0·156	0·175	0·206	0·223
	TOTAL HEAT *per second per square foot of* External *surface.*								
24	From circulating water, $H+C$ Th. U.	6·5	10·9	14·5	15·6	12·6	15·9	18·5	19·8
25	From steam condensed, $H+C+R$ Th. U.	—	10·9	14·0	15·3	13·0	14·8	17·4	18·9
	NET HEAT *per second per square foot of* Internal *surface.*								
26	From circulating water, $\{(H+O)-C\}\times N$ . . Th. U.	7·8	13·8	18·4	19·9	14·7	18·9	22·2	23·8
27	From steam condensed, $\{(H+C+R)-(C+R)\}\times N$ . . Th. U.	—	12·1	16·2	17·9	13·4	15·6	18·9	20·8
28	Estimated Thickness of film of condensed steam deposited . . . inch	0·0017	0·0009	0·0020	0·0023	0·0030	0·0029	0·0029	0·0025

TABLE 1 (*continued from preceding page*).

Transmission of Heat from Surface Condensation through Metal Cylinders.

			Series 7. *See Figs.* 12 *and* 13, *Plate* 118.							
1	Material and Thickness of Cylinder		Steel, 1–32 inch thick.							
2	Condition of surfaces		Smooth both sides.							
3	Nature of steam admission		In one jet.							
4	Radii, outside and inside		1·44 and 1·40 inch.							
5	Effective Areas, outside and inside		0·174 and 0·170 square foot.							
6	Ratio of outside area to inside	*N*	1·02 to 1·00							
8	Heat per second per square foot of external surface: Conduction through covers	*C*	0·3 thermal unit.				0·9 thermal unit.			
9	Heat per second per square foot of external surface: Radiation	*R*	1·3 thermal unit.				1·5 thermal unit.			
	Number of trial	No.	189	190	191	192	196	193	194	195
13	Temperature of Circulating Water: initial	Fahr.	87·0°	79·8°	77·7°	69·3°	73·0°	78·6°	72·2°	71·2°
14	Temperature of Circulating Water: final, observed	Fahr.	180·5°	138·5°	116·0°	96·9°	201·8°	168·7°	131·4°	111·5°
15	Temperature of Circulating Water: „ calculated	Fahr.	172°	136°	116°	99°	207°	163°	136°	116°

TABLE 1 (*continued from opposite page*).

			Series 7.							
	Number of trial	No.	189	190	191	192	196	193	194	195
16	Circulating Water: Velocity	feet per sec.	0·078	0·172	0·268	0·386	0·098	0·158	0·260	0·387
17	Circulating Water: Weight per minute	lbs.	1·88	4·12	6·40	9·23	2·36	3·78	6·21	9·25
18	Circulating Water: „ per sec. per sq. ft. of inside surface	lb.	0·18	0·40	0·62	0·89	0·22	0·37	0·60	0·90
22	Steam, Temperature	Fahr.	230°	228°	228°	227°	269°	269°	269°	268°
23	„ Weight condensed per minute	lb.	0·193	0·217	0·255	0·268	0·301	0·344	0·369	0·376
	TOTAL HEAT *per second per square foot of* External *surface.*									
24	From circulating water, $H+C$	Th. U.	16·8	23·1	23·4	24·4	31·3	32·6	35·2	35·7
25	From steam condensed, $H+C+R$	Th. U.	17·6	22·5	23·2	24·4	26·6	30·4	32·6	33·3
	NET HEAT *per second per square foot of* Internal *surface.*									
26	From circulating water, $\{(H+C)-C\}\times N$	Th. U.	16·8	23·2	23·6	24·6	31·0	32·3	35·0	35·5
27	From steam condensed, $\{(H+C+R)-(C+R)\}\times N$	Th. U.	16·3	21·3	22·0	23·3	24·7	28·6	30·8	31·5

TABLE 1 (*continued from preceding page*).

Transmission of Heat from Surface Condensation through Metal Cylinders.

		Series 8. *See Figs.* 14 *and* 15, *Plate* 118.					
1	Material and Thickness of Cylinder	Copper, 2-32nds inch thick.					
2	Condition of surfaces	Smooth both sides.					
3	Nature of steam admission	In one jet.					
4	Radii, outside and inside	1·50 and 1·44 inch.					
5	Effective Areas, outside and inside	0·182 and 0·175 square foot.					
6	Ratio of outside area to inside . . . *N*	1·04 to 1·00					
8	Heat per second per square foot of external area — Conduction through covers . . *C*	0·3 thermal unit.					
9	Heat per second per square foot of external area — Radiation . . . *R*	1·3 thermal unit.					
	Number of trial . . . No.	211	212	213	214	215	216
13	Temperature of Circulating Water — initial . . . Fahr.	86·0°	80·6°	72·9°	71·5°	71·0°	74·2°
14	Temperature of Circulating Water — final, observed . . . Fahr.	183·4°	142·1°	115·8°	101·4°	107·4°	127·2°
15	Temperature of Circulating Water — „ calculated . . . Fahr.	183°	139°	113°	102°	116°	133°

TABLE 1 (*concluded from page* 510).

				Series 8.					
	Number of trial		No.	211	212	213	214	215	216
16	Circulating Water	Velocity	feet per sec.	0·052	0·122	0·201	0·298	0·299	0·188
17		Weight per minute	lbs.	1·63	3·83	6·41	9·31	9·37	5·90
18		„ per second per sq. ft. of inside surface	lb.	0·17	0·37	0·62	0·90	0·91	0·57
22	Steam, Temperature		Fahr.	227°	217°	213°	212°	231°	231°
23	„ Weight condensed per minute		lb.	0·173	0·223	0·259	0·290	0·358	0·319
	TOTAL HEAT *per second per square foot of* External *surface.*								
24	From circulating water, $H+C$		Th. U.	14·5	21·6	25·2	25·5	31·3	28·7
25	From steam condensed, $H+C+R$		Th. U.	15·1	19·6	22·9	25·6	31·2	27·9
	NET HEAT *per second per square foot of* Internal *surface.*								
26	From circulating water, $\{(H+C)-C\}\times N$		Th. U.	14·8	22·2	25·9	26·2	32·3	29·5
27	From steam condensed, $\{(H+C+R)-(C+R)\}\times N$		Th. U.	14·0	18·8	22·2	25·0	30·8	27·4

TABLE 2.—*Nichol's Experiments.*

Position of Tube; and No. of Experiment.	Circulating Water.					Steam Temperature.
	Velocity per second.	Weight per sq. foot per second.	Temperature.			
			Initial observed.	Final observed.	Final calculated.	
No.	Feet.	Lb.	Fahr.	Fahr.	Fahr.	Fahr.
V 1	1·35	0·18	58°	140°	140°	255°
V 2	4·63	0·63	,,	93½°	93°	,,
V 3	6·50	0·88	,,	85°	85°	,,
H 4	1·30	0·18	,,	165°	165°	,,
H 5	5·12	0·70	,,	101°	100°	,,
H 6	6·92	0·94	,,	94½°	94°	,,

V = Vertical tube. H = Horizontal tube.

TABLE 3 (*continued to page* 525).—*Hagemann's Experiments.*

4–5	0·30	0·06	79°	159°	146°	212°
6–7	0·46	0·09	90°	146°	145°	,,
8–9	0·89	0·17	98°	138°	138°	,,
10–11	2·60	0·51	106°	133°	130°	,,
11*a*	4·06	0·79	106°	127°	124°	,,
11*b*	5·57	1·12	109°	124½°	125°	,,
11*c*	5·67	1·13	106°	123°	123°	,,
11*d*	5·93	1·16	123°	136½°	138°	,,
12	1·02	0·20	192°	200°	205°	,,
13	1·02	0·20	188°	198°	202°	,,
14	1·03	0·20	164°	183°	187°	,,
15	1·03	0·20	134°	163°	164°	,,
16	1·04	0·20	118°	152°	152°	213°
17	1·02	0·20	104°	143°	141°	,,
18	1·03	0·20	96°	135°	135°	,,
19	1·02	0·20	84°	125°	125°	,,

TABLE 3 (*continued from opposite page*).—*Hagemann's Experiments.*

Experiment.	Circulating Water.					Steam Temperature.
	Velocity per second.	Weight per sq. foot per second.	Temperature.			
			Initial observed.	Final observed.	Final calculated.	
No.	Feet.	Lb.	Fahr.	Fahr.	Fahr.	Fahr.
20	1·04	0·20	61°	107°	106°	213°
21	2·23	0·44	191°	198°	200°	212°
22	2·19	0·43	190°	197°	201°	,,
23	2·09	0·41	187°	195°	199°	,,
24	2·07	0·41	159°	176°	177°	,,
25	2·08	0·41	159°	175°	177°	,,
26	2·08	0·41	131°	154°	153°	,,
27	2·09	0·41	105°	133°	132°	,,
28	2·10	0·41	87°	115°	116°	,,
29	2·08	0·41	50°	83½°	83°	,,
30–31	3·35	0·66	195°	199°	202°	,,
32	3·31	0·65	186°	193°	196°	,,
33	3·41	0·67	141°	158°	158°	,,
34	3·40	0·67	110°	134°	131°	,,
35	3·38	0·66	49°	78°	76°	,,
36	5·38	1·05	193°	196½°	200°	,,
37	5·44	1·06	162°	173°	173°	,,
38	5·46	1·07	127°	143°	142°	,,
39	5·38	1·05	49°	72°	71°	,,
40	5·50	1·07	49°	71°	71°	,,
56	1·94	0·38	42°	87°	87°	220°
57	1·87	0·37	42°	98°	98°	239°
58	1·83	0·36	42°	104°	103°	255°
59	1·87	0·37	42°	117°	114°	280°
60–61	2·14	0·42	42°	85°	77°	213°
62	2·14	0·42	43°	96°	92°	235°

TABLE 3 (*continued from preceding page*).—*Hagemann's Experiments.*

Experiment.	Circulating Water.					Steam Temperature.
	Velocity per second.	Weight per sq. foot per second.	Temperature.			
			Initial observed.	Final observed.	Final calculated.	
No.	Feet.	Lb.	Fahr.	Fahr.	Fahr.	Fahr.
63	2·14	0·42	43°	100°	97°	248°
64	2·14	0·42	,,	102°	98°	252°
65	2·14	0·42	,,	112°	106°	272°
66	2·95	0·58	,,	79°	71°	213°
67	2·95	0·58	,,	83°	81°	225°
68	2·95	0·58	,,	88°	85°	241°
69	2·95	0·58	,,	90°	88°	247°
70–71	2·95	0·58	,,	96°	92°	269°
72–73	4·59	0·91	,,	83°	76°	212°
74	4·59	0·91	44°	72°	72°	221°
75	4·59	0·91	44°	74°	74°	236°
76–77	4·59	0·91	43°	79°	78°	258°
78–79	4·59	0·91	43°	80°	81°	266°
80	2·04	0·40	44°	105°	103°	260°
81	2·04	0·40	,,	103°	104°	255°
82	2·04	0·40	,,	99°	101°	248°
83	2·04	0·40	,,	95°	96°	236°
84	2·04	0·40	43°	88°	87°	221°
85	2·08	0·41	44°	83°	76°	212°
86	2·04	0·40	,,	80°	77°	207°
87	2·04	0·40	,,	80°	77°	204°
88	2·04	0·40	,,	75°	76°	190°
89	1·93	0·37	58°	103°	102°	223°
90	1·82	0·36	59°	113°	112°	240°
91	1·82	0·36	56°	117°	117°	256°
92	1·82	0·36	55°	130°	126°	282°

TABLE 3 (*concluded from page* 522).—*Hagemann's Experiments.*

Experiment.	Circulating Water.					Steam Temperature.
	Velocity per second.	Weight per sq. foot per second.	Temperature. Initial observed.	Final observed.	Final calculated.	
No.	Feet.	Lb.	Fahr.	Fahr.	Fahr.	Fahr.
93–94	3·19	0·62	139°	158°	164°	229°
95–96	3·19	0·62	139°	165°	171°	252°
97–99	3·19	0·62	140°	172°	176°	275°
100	2·67	0·52	176°	209°	210°	277°
101	2·62	0·51	180°	212°	213°	278°
102	2·67	0·52	167°	201°	204°	278°
103	2·75	0·54	140°	180°	177°	276°
104	2·77	0·54	137°	175°	178°	277°
105	2·77	0·54	126°	165°	168°	277°
106	2·78	0·55	119°	160°	162°	276°
107	2·77	0·54	113°	155°	157°	277°
108	2·77	0·54	103°	147°	148°	277°
109	2·77	0·54	98°	144°	144°	278°
110	2·77	0·54	89°	136°	138°	278°
111	2·75	0·54	60°	110°	108°	278°
112	2·75	0·54	43°	98°	97°	277°
a–b	2·90	0·57	45°	83°	83°	229°
c–d	2·89	0·56	92°	122°	125°	230°
e	2·89	0·56	101°	131°	134°	231°
f–g	2·89	0·56	111°	138°	142°	230°
h	3·18	0·61	139°	158°	157°	212°
113–14	3·05	0·60	44°	75°	73°	212°
115–16	3·00	0·59	44°	84°	86°	241°
117–18	3·02	0·59	44°	87°	88°	252°
119–20	3·02	0·59	44°	90°	90°	261°
121–22	3·02	0·59	44°	93°	94°	274°

Discussion.

Mr. Henry Davey, Member of Council, noticed that one of the objects in making these experiments for determining the transmission of heat through metals had been that they might be of use for determining the areas required in steam-jacketed cylinders and condenser tubes (page 501). In regard to the latter, there was one essential difference to be observed between the mode of condensation with condenser tubes and that carried out in these experiments. Here there was a constant transmission of heat through the metal, constant temperature on the outside, and constant temperature on the inside. In condenser tubes there was practically constant or nearly constant temperature on the inside, when the steam was as usual condensed on the outside of the tubes; but the steam had to be condensed intermittently; there was not a constant flow of steam to the outside of the tubes. Not only had the condensation to take place intermittently, but the bulk of it had to take place in a small fraction of time. In a rotative engine the condensation of the steam took place almost entirely in the small portion of time during which the engine was passing the dead point; if it were not so, there would be much more back-pressure shown on the indicator diagram at the beginning of the exhaust line. The condenser therefore presented tubes of metal which had been cooled during the stroke of the engine, and at the end of the stroke a large volume of steam was suddenly thrown upon their surfaces; consequently the amount of surface to be provided must be sufficient for quick condensation. From these experiments he had no doubt Colonel English would be able to deduce a mathematical formula which would be applicable to condenser tubes. In another respect moreover it would be noticed that the conditions of condenser tubes were not the same as those dealt with in the experiments. It had to be borne in mind that steam passing through the engine was usually contaminated with grease or oil, which became deposited upon the condenser tubes, and to a certain extent reduced their condensing capacity. There was also the furring of the tubes inside, which was due to solid deposit from the circulating water passing through them.

Mr. W. G. Walker had recently carried out a few experiments on the transfer of heat through plates with variously arranged surfaces, and in contact with steam, air, and water, dealing mainly with the effect of internal and external ribs soldered on a metallic cylinder. The ribbed cylinders had been tried under various conditions, being filled with cold water, which was allowed to absorb heat from steam surrounding the cylinder; and the heat absorbed was subsequently radiated out into the air, or passed by conduction into a tank of cold water in which the warmed cylinder was then submerged. The presence of the ribs increased to a considerable extent the speed of the transfer of heat, either in absorbing heat from the external steam or in radiating it out into the air. But when the warmed cylinder was submerged in the cold water, the ribs had practically no effect on the transfer of heat. It was also noticed that the ribbed cylinder was not so efficient in absorbing heat from the steam as in radiating it out into the air; and this was probably due to the condensed film of water which was deposited on the external surface of the cylinder when absorbing heat from the steam. Coils of copper wire about 1–16th inch thick had also been wound round the cylinder, with a short distance between them; and in then absorbing heat from the steam a considerable layer of water of about 1–16th inch thickness was deposited, which could not easily be thrown off; this retarded the transfer of heat to a considerable extent. A roughened surface was also tried, and the same retarding effect was noticed as with the coils of copper wire.

Mr. A. H. Barker thought that these experiments were well designed to throw light on the transmission of heat through the tubes of a condenser; but that, if they had been intended to apply to steam-jackets, there ought to have been steam on both sides of the metallic conducting wall: high-pressure steam on one side, and comparatively low-pressure steam on the other. If there was water on one side of the conducting wall and steam on the other, the heat transmission he thought would not be at all similar to what it would be if there was steam on both sides. The steam-jacket he regarded as a device for preventing a film of water from condensing on the

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inside of a steam cylinder; and he imagined that, if a steam-jacket were effective in its action, no such film would be deposited. If this view was correct, it would seem that the experiments now described had no bearing upon the subject of steam-jacketed cylinders. The method described in page 503 and illustrated in Figs. 2 and 3, Plate 116, for determining the amount of the correction for heat conducted through the top and bottom covers of the experimental apparatus, would not be accurate, he thought, because it appeared from Fig. 5 that the stream of water, entering through the central inlet pipe at the bottom, first spread radially over the circular cover, then travelled up the inside of the cylindrical metallic wall, and then passed across radially beneath the top cover to the central outlet pipe. A large part of the heat that came through the covers therefore would apparently get into the water while it was passing radially over the bottom cover and under the top cover. But according to the arrangement shown in Fig. 3, it seemed to him that the whole of the heat there transmitted through the covers must find its way to the central inlet and outlet pipes before it could pass into the water; and consequently that the amount of the heat which got into the water by conduction along the covers in Fig. 3, where there was no radial flow of water over the surfaces of the covers, would not be so large as when a great deal of heat was taken up by the water while it was flowing radially in Fig. 5 over the faces of the covers.

Mr. E. Tremlett Carter, referring to the statement in page 502 that in these trials it had not been possible to trace the slightest appearance of cloudiness or mist in the condensing steam, wished to point out that in a steam-engine cylinder the rapid expansion of the steam, being approximately adiabatic, would necessarily tend to produce water, through the transformation of heat into work, apart from the abstraction of heat through the cylinder walls; and he asked whether the experiments were intended to show, and whether the above statement was intended to imply, that in the adiabatic expansion of steam, accompanied by the formation of water internally through the abstraction of energy from the steam, cloudiness was not produced; or whether the observation applied merely to the condensation by abstraction of heat through the walls. It seemed to him that, if cloudiness was produced in the adiabatic or approximately adiabatic expansion of steam in an engine cylinder, the behaviour of the cylinder walls would be intrinsically different from that which would occur in a surface condenser, where there was saturated steam to be condensed which was not doing work, and where the walls of the condenser tubes had merely to abstract heat from steam which was not cloudy.

Mr. Druitt Halpin considered great service had been done by these experiments, and their value would be largely enhanced by the addition in Tables 2 and 3 of the actual heat transmission, per unit of time and of surface and of difference in temperature, in Nichol's and Hagemann's experiments. In page 505 he did not understand what was meant to be implied by the statement that there was no drop in temperature on entering or leaving the metal. Though there might not be a drop in the temperature, there might be a drop in the velocity of transmission. The receptivity or facility of entrance into the metal, and the conductivity or power of transmission within its substance, he was certainly of opinion were two totally different quantities. This he thought might reasonably be assumed to be true from the simple fact that a boiler plate, half or three-quarters of an inch thick, might be exposed to a fairly heavy fire without getting into any trouble; but if two thicknesses of the same plate were riveted together, however closely and tightly, the outer plate would not stand the fire, and would become burnt, because there was a severance of the molecular continuity in the middle of the thickness, which was always a source of trouble. Thus it would appear that the power of entrance and the power of passing through were totally different quantities.

The difference in the rate of heat transmission, due to difference in the velocity of the cooling water, had been alluded to in the paper (page 505), but the relation between the two did not seem to have been clearly followed out with figures. For surface condensers this was of course the most serious question; because where the velocities alone

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were widely different, while all other conditions were exactly similar, the rates of condensation also differed widely. Having recently had an opportunity of noting the working of an Atkinson feed-water heater, and of taking the ingoing and outgoing temperatures, he had found that in that instance there were 40 thermal units passing into the water per hour per square foot of heating surface and per degree of difference in temperature; but under the circumstances the velocity of the water over the heating surface was only 16 feet an hour, which was a properly arranged speed for such an apparatus, because it was wanted to deposit there any sediment or dirt which might be contained in the water. But in a marine condenser, instead of a speed of 16 feet an hour, speeds of 300 to 600 feet a minute were employed; and thereby, instead of 40 units per hour, the transmission was brought up to 400 units per hour per square foot of cooling surface and per degree of difference in temperature. As to condensation being intermittent in the surface condenser of a steam engine (page 526), ordinarily the volume of a surface condenser was so large in proportion to the engine cylinders that the condenser might from that point of view be compared with the air vessel of a pumping engine at a water works; and for all practical purposes he should think condensation might be said to be going on uninterruptedly.

Mr. Michael Longridge mentioned that in foreign countries it had sometimes been the practice to jacket cylinders by passing the steam through the jacket into the cylinder itself. That was a highly convenient arrangement in many ways: it ensured freedom from air and water in the jacket, and freedom from breaking of jacket joints, which was often associated with the turning of steam into a water-logged jacket. English engineers had held aloof from it, he believed through the idea that, if the cylinder were so jacketed, the steam introduced into the cylinder through the jacket must be wet steam. One of the most important lessons taught by these experiments was that this would not be the result, because apparently the whole of the water in the steam would be deposited upon the surfaces of the jacket, and there would be no water left in the steam at all.

Furthermore, not only would the steam be dry, but, notwithstanding its intermittent supply consequent upon the alternate action of the valve, it would not sweep the water off the jacket surfaces into the cylinder itself. This was a point which he thought was to be noted from these experiments.

Lt.-Colonel English agreed with Mr. Davey (page 526) in believing that nearly all the condensation in a steam engine took place very quickly indeed; this he thought was fully confirmed by the experiments. If the figures were worked out, it would be found that under favourable circumstances condensation did take place at a much greater rate than it had generally been considered to do; and therefore that a great deal of condensation in a steam engine might take place immediately that the steam was admitted into the condenser.

Mr. Walker's experiments (page 527) appeared to confirm those described in the paper, as to the effect of a film of water. It had not been mentioned however whether in those experiments any quantitative results had been obtained; it was highly desirable in experiments of this kind to get them, if possible.

The object of a steam-jacket, as understood by Mr. Barker (page 527), was to prevent a film of water from condensing in the interior of the cylinder. He himself would rather say that the object was to try to prevent it from doing so; for he believed it was an almost universal opinion that in nearly every cylinder initial condensation did occur. As to the correction for heat passing through the covers in the experimental apparatus (page 528), the same india-rubber washers were used with the inner glass cylinder that were interposed between the metal cylinders and the cast-iron covers; all the heat therefore for which correction was required had to pass in both cases through the same circumferential section of cover, so that, by adjusting the amount of cooling water, the same thermal gradient could be maintained through this section.

With regard to adiabatic expansion of steam producing cloudiness (page 528), in many of these experiments there had been considerable adiabatic expansion, for the reason that the condensation went on at a

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much greater rate than that at which the steam could be supplied through the admission pipe; therefore the pressure could not be kept up, and the steam necessarily expanded considerably before it condensed. All that the authors had said was that they had not been able to trace in any experiment the slightest appearance of cloudiness, though they had looked carefully for it.

The amount of transmission of heat per degree of difference in temperature, as desired by Mr. Halpin (page 529), he thought could be got from the tables already printed. The reason why columns to that effect had not been inserted was that the transmission of heat had been found to be not a simple function of the difference in temperature: it was more nearly as the square root of the difference in temperature. The transmission of 400 thermal units per square foot per hour per degree of difference in temperature in a marine surface-condenser (page 530) would be about half the rate obtained in some of these experiments, as shown in Table 4, page 534.

With Mr. Longridge's remarks (page 530) he quite agreed, as to the effects of jacketing cylinders by passing the steam through the jackets on its way into the cylinders.

Mr. Bryan Donkin, Member of Council, said that upon the question of the heat transmission going on continuously or not continuously he had compiled in Table 4 (pages 534–535), since the paper was written, chiefly from his own experiments some examples bearing upon this point in the transmission of heat through walls of cast-iron, wrought-iron, brass, and copper, in economiser pipes, steam boilers, condenser tubes, steam-engine and gas-engine cylinders, and small vertical cylinders. The heat passed from hot gases to water, and from steam to steam and to water, through different thicknesses of metal. It made a difference whether the metal surfaces were vertical or horizontal.* Transmission of heat through a piece of condenser tube, encrusted with a film of carbonate of lime on the inside and with a deposit of dirt and grease or oil on the outside, could be readily tested in the experimental apparatus described in the paper; by trying it first in its original dirty condition, and afterwards when cleaned first on one side and then on the other, the difference of transmission due to the condition of the two surfaces jointly and separately could be ascertained. In the transmission of heat through two plates riveted together (page 529), if they were not in absolute metallic contact over their whole surfaces, there would be air between them, which would materially retard the passage of heat.

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* There have been published in Germany 125 experiments by Dr. Wiebe on the transmission of heat through horizontal steel and copper plates, 10 inches diameter and of various thicknesses, with hot gases on one side evaporating hot water on the other. See "Thätigkeit der Physicalischen Technischen Reichs-anstalt," April 1895 and February 1896.

The President said the authors had evidently taken considerable trouble in preparing the experimental apparatus and carrying out the trials and bringing the results before the members, who he was sure would desire to pass a hearty vote of thanks to them.

(Mr. Bryan Donkin.)

TABLE 4.—*Heat Transmission* CONTINUOUS
through Walls of Cast-Iron, Wrought-Iron, Brass, and Copper;
in experiments with Economiser Pipes, Steam Boilers, small Cylinders, and Condenser Tubes.
Heat passing from Hot Gases to Water, and from Steam to Water.

Number of Experiment.	Position and Description of Wall.	Metal and Thickness of Wall.	Hotter side of Wall.		Cooler side of Wall.		Mean Difference in Temperature.	Heat Transmission per sq. ft. per hour.	
			Medium.	Mean Temperature of medium.	Medium.	Mean Temperature of medium.		Thermal Units.	Per degree of mean difference in temp.
No.				Fahr.		Fahr.	Fahr.	Th. U.	Th. U.
1	Vertical Pipes 4 ins. outside diam. of Economiser.	Cast-Iron 3–8ths inch	Hot Gases	550°	Water	150°	400°	972	2½
2	Horizontal Surface of Steam Boilers 5 to 7 feet diameter.	Wrought-Iron half inch	Hot Gases	800°	Water	300°	500°	4,500	9
3	Vertical Cylinder 1 inch inside diam.	Cast-Iron 1 inch	Steam in Jacket	275°	Water inside Cylinder or Tube	85°	190°	21,600	113½
4	Vertical Cylinder 2 ins. inside diam.	Cast-Iron half inch		275°		85°	190°	29,160	153½
5	Vertical Cylinder 2¼ ins. inside diam.	Cast-Iron 1–3rd inch		275°		85°	190°	57,600	303
6	Vertical Tube 1 15/16 inch outside diam. Hagemann (Table 3)	Brass 3–32nds inch		265°		61°	204°	65,520	321
7	Vertical Cylinder 10⅛ ins. inside diam. Morison (1892, p. 485)	Cast-Iron 13–32nds inch		240° 324°		212° 212°	28° 112°	10,080 45,610	360 407
8	Vertical Tube ¾ inch outside diam. Horizontal ditto Nichol (Table 2)	Brass 1–20th inch		255° 255°		75° 79°	180° 176°	80,640 107,640	448 612
9	Vertical Cylinder 3 ins. outside diam.	Copper 1–16th inch		231°		89°	142°	112,320	791

TABLE 4 (*continued*).—*Heat Transmission* NOT CONTINUOUS *through Walls of Cast-Iron and Copper;*
in experiments with Gas-engine and Steam-engine Cylinders, and Condenser Tubes.
Heat passing from Hot Gases to Water, and from Steam to Steam and to Water.

Number of Experiment.	Position and Description of Wall.	Metal and Thickness of Wall.	Hotter side of Wall.		Cooler side of Wall.		Mean Difference in Temperature.	Heat Transmission per sq. ft. per hour.	
			Medium.	Mean Temperature of medium.	Medium.	Mean Temperature of medium.		Thermal Units.	Per degree of mean difference in temp.
No.				Fahr.		Fahr.	Fahr.	Th. U.	Th. U.
10	Horizontal Cylinder $8\frac{1}{2}$ inches diameter of Gas engine.	Cast-Iron 7–8ths inch	Hot Gases in Cyl.	2,000°	Water in Jacket	100°	1,900°	53,280	28
11	Vertical High-p. Cyl. 6 inches diameter.	Cast-Iron 1 inch	Steam in Jacket	299°	Steam inside Cylinder	222°	77°	2,700	35
12	Vertical Inter. Cyl. 22 inches diameter of triple engine.	Cast-Iron 1 inch		318°		242°	76°	4,030	53
13	Vertical Low-p. Cyl. 36 inches diameter of triple engine.	Cast-Iron $1\frac{1}{8}$ inch		237°		175°	62°	3,530	57
14	Vertical High-p. Cyl. 15 inches diameter of triple engine.	Cast-Iron 1 inch		318°		315°	33°	2,020	61
15	40 Horizontal Tubes $\frac{3}{4}$ inch diameter of Surface Condenser.	Copper 1–16th inch	Exhaust Steam outside Tubes	145°	Water inside Tubes	85°	60°	6,300	105

BREAKDOWNS OF STATIONARY STEAM-ENGINES.

By Mr. MICHAEL LONGRIDGE, of Manchester.

Having been engaged during the last twenty years in the inspection and insurance of Factory Engines, and having seen something of the weaknesses and frailties leading to their Breakdowns, it occurred to the author to offer to the Institution a short digest of his experience on a subject which is naturally of much practical interest to Mechanical Engineers. The present paper is primarily statistical; but the statements of fact are interspersed with suggestions as to their meaning, whenever the latter seems to have been ascertained. The statistics are derived from the last thousand breakdowns with which the writer had to deal previously to 31st December 1894. The number is no doubt small for forming the basis of a statistical enquiry; but the labour of searching more deeply into the records of the past forbade its being exceeded. These breakdowns have been analysed and classified, in order to show which parts of the engines gave way first; and then the breakdowns of the different parts have been subdivided into groups, in order to show as far as possible the various causes to which the breakages of each of the several parts were due. In some instances, where the causes of damage are well defined, the writer has ventured to suggest the steps which should be taken to avoid them; in others, where they can less clearly be distinguished, it is left to the designers, makers, and users of steam engines to draw their own conclusions from the evidence. The paper is not intended as a treatise on steam-engine design; but may be likened rather to a mariner's chart, whereon are marked the rocks and shoals round which the wrecks lie thickest.

The results of the first analysis or classification are as follows:—

TABLE 1.

Parts which appear to have broken first, and Number of cases.

Valves and valve gear	213
Spur wheels	124
Air-pump motions	121
Air-pump buckets and valves	88
Columns, entablatures, bedplates, and pedestals	86
Main shafts	49
Connecting rods	41
Cylinders and valve-chests	35
Parallel motions	35
Governors and governor gear	28
Piston rods	27
Piston-rod cross-heads	27
Pistons	22
McNaught and main links	22
Fly-wheels	19
Air-pumps and condensers	13
Cranks	12
Gudgeons in beams	12
Crank-pins	11
Beams	6
Slide-bars	5
Ropes	3
Entire smash, no cause ascertained	1
Total number of Breakdowns	1000

It is unnecessary to discuss this list, as it represents merely the preliminary sorting of the breakdowns into classes suitable for closer examination. But before proceeding with this examination, it may be premised in the first place that the engine, as the word is used in the present paper, is limited by the crank-shaft and the wheels upon it. The spur pinion upon what is called in Lancashire the "second-motion" shaft, that is, the pinion which is geared with the driving wheel upon the engine crank-shaft, is not considered as a part of the engine. It is important to notice this distinction, because the breakages of spur wheels would have been much more numerous than stated in Table 1, if the breakages of pinions had been included in the list. The risk attending the use of spur gearing therefore is not by any means to be estimated by the proportion 124 per 1000. And secondly, considering the number of accidents which occur through the failure of bolts, studs, split pins, and other fastenings, it might be expected that the fastenings generally would have been assigned to a special class; but the author came to the conclusion that it would suit the present purpose better to include the fastenings of each part with the part itself. Thus the bolts securing piston covers to pistons are classified with pistons, the gibs and cotters or bolts in connecting rods are considered as parts of the connecting rods, and so on.

Valves and Valve Gear.—The 213 breakages under this head may be subdivided as in Table 2.

The results of the subdivision of this class are rather disappointing. The miscellaneous character of the parts included in it, the uncertainty as to the stresses they had to bear, and the difficulty of ascertaining all the circumstances attending their breakage, are antagonistic both to brevity and to distinctness. Still something may be learnt from it. As most of the breakages to which no cause could be assigned were really due rather to inability to endure the ordinary conditions of work than to the action of any abnormal stresses, it becomes evident that there is room for considerable improvement in the designing of valve-gears, as regards both the strength and the arrangement and workmanship of the various fastenings.

Of the forty-six valve spindles in group A, no fewer than thirty-four broke at screw threads. Most of these were of steel, and the appearance of the fractured surfaces nearly always showed that the fracture had commenced at the bottom of the thread and had extended gradually through the spindle. Doubtless screw threads are necessary for purposes of adjustment; but if used, they should not be of the ordinary V shape; gas threads are better, and round

TABLE 2.—*Valves and Valve Gear.*

Cause or nature of Breakage, and Number of cases.

A	Valve spindles broken :—		
	Weakness of screw threads	34	
	Sundry causes	12	46
B	Eccentric straps broken :—		
	Cause not ascertained	11	
	Weakness	8	
	Various causes	5	24
C	Rocking shafts and levers broken :—		
	Weakness, wear and tear, and causes not ascertained		23
D	Nuts, cotters, and pins, for securing valves to spindles, got loose		21
E	Eccentric rods broken :—		
	At screw threads	9	
	Weakness	5	
	Cause not ascertained	4	18
F	Slide valves broken		17
G	Eccentrics, nuts, cotters, or other fastenings of valve motions, got loose		13
H	Brass pieces, pinned to valves for increasing the lap, came off		11
I	Trip motion of Corliss valve-gear, broken :—		
	Dashpot rods, from vibration	4	
	Other parts, cause not ascertained	3	7
J	Brackets for Corliss valve-spindles		6
K	Eccentrics broken		5
L	Sundry breakdowns		22
	Total breakdowns of Valves and Valve Gear		213

threads are best. Moreover the joints in the valve gear should have adjustable brasses with large surfaces, to take up wear. And above all, cross-bending stresses, however slight, should be rendered impossible by the use of rigid and properly adjusted guides.

The causes of the twenty-four breakages of eccentric straps in group B were generally obscure. Some broke from heating; two through the valve motion getting jammed by foreign bodies; but most from weakness, particularly weakness of the lugs or bolts by which the two halves of the straps were joined together.

To weakness also were due most of the twenty-three breakages of rocking shafts and levers in group C. Or, if "weakness" be objected to in the absence of definite proof or calculation, " inability to bear the ordinary wear and tear of working " may be substituted.

Of the twenty-one breakdowns in group D, caused by fastenings getting loose inside valve-chests, twelve were traced to nuts coming off valve spindles or to corrosion of screw threads, and five to cotters getting loose. Three were due to the breaking of buckles or bridles from weakness; and one to the excursions of a lump of iron, which had been bolted to the inside of a valve-chest in order to reduce its capacity. Probably the best way of fastening a slide-valve to its spindle is to thread it upon a plain tube a bare 1–32nd inch longer than itself; to thread this tube upon the spindle; and to secure it by nuts screwed hard up against each end of the tube. If the nuts be placed in recesses in the back of the valve, it becomes absolutely impossible for them to get off the spindle. It is also advisable to provide handholes in the valve chests or in the valve-chest doors of large engines, in order to facilitate examination.

Of the eighteen broken eccentric-rods in group E, nine gave way at the screwed ends, by which they were attached to the eccentric straps: exemplifying the fatal effect of cross-bending stresses upon V threads. Nine broke in the body of the rod without ascertained cause.

The breakages of valves in group F were due for the most part to weakness. In five instances the faces of common slide-valves were broken off from the exhaust hollow, probably through slamming against the cylinder face. In two the cast-iron jaws which received the T headed ends of the valve spindles were broken off. Two valves having expansion plates on the back parted across the nearer or front port-way; the front piece, to which the spindle was fastened, became detached from the back part, in which the exhaust hollow was cast. The remaining eight cases were of a miscellaneous character.

The eleven breakdowns resulting from the breaking loose of strips of brass pinned to the edges of slide-valves or ports need no explanation. The remedy is evident.

Spur Gearing.—In this class, as already explained, only the driving wheels upon the engine main-shafts were counted, the driven wheels or pinions being excluded. Had the latter been counted also, the breakages of spur gearing would have been nearly doubled. Moreover there were many instances in which a wheel suffered a series of misfortunes, one following close upon another, and all arising from the same cause. In such instances the whole series of breakages is counted as only one breakdown; this also will make spur gearing appear less troublesome than it really is.

The 124 breakdowns in this class may be grouped as follows:—

TABLE 3.—*Spur Gearing.*

Cause or nature of Breakage, and Number of cases.

A	Backlash from belt or rope drums on second-motion shafts	23
B	Vibration due to high speed, heavy load, insufficient fly-wheel, and small pinions	19
C	Excessive stress due to teeth bearing on their corners and up to their points	16
D	High speed and irregular pitch	11
E	Bolts or pieces of broken teeth had got between wheels	10
F	No evidence as to causes	9
G	Fractures from internal stress	7
H	Insufficient or loose supports	6
I	Mortice wheels stripped	5
J	Putting new pinions to work with old wheels	4
K	Small size of pinions	5
L	Sundry causes and pure accident	9
	Total breakdowns of Spur Gearing	124

In group A the word "backlash" is used in the extended sense in which it is understood in Lancashire and Yorkshire, including not only backlash proper, but also break of contact between the working faces of the teeth of the two wheels when the driven wheel overruns the driver without actual backlash. To place rope or belt drums of any considerable size upon shafts driven by spur gearing is nearly always dangerous. Such drums are often put upon second-motion shafts, to replace existing gearing or to drive additional machinery. As they have generally to be got into existing buildings where there is little room to spare, there is often a great temptation to keep down their width and to adopt a high circumferential speed. This alone is sufficient to make the pinion on the second-motion shaft overrun the spur wheel on the main shaft of the engine; but when in addition the ropes or belts bounce, as they sometimes do if long, unless the engine has a powerful fly-wheel the effect is sure to be disastrous to the gearing. In fact it may be safely stated that heavy rope or belt driving should never be placed in sequence to spur gearing, except after special investigation by a competent engineer fully aware of the risk thereby incurred. The conditions necessary to success are, first and most important, a powerful fly-wheel on the engine crank-shaft; secondly, a fairly uniform load, or a load which changes but slowly; thirdly, slow speed of ropes. It is true that, if the speed of the ropes be reduced, their number and weight must be increased; but it must be remembered that, while the capacity of a rope to transmit power varies at moderate velocities approximately as the speed, its capacity for doing mischief, being measured by its energy, varies as the speed squared. Hence, although two ropes running at 2,000 feet per minute may be required to transmit the same power as one running at 4,000 feet, the two will have only half the power of the one in respect of damaging the gearing. The fact that twenty-three breakdowns have occurred, among the limited number of engines which turn rope-drives through gearing, is strong evidence of the danger of the arrangement.

For want of a more suitable expression, the nineteen breakdowns in group B have been ascribed to vibration. The cause is actually wear and tear of a particular kind of segmental spur-wheel working under particular conditions, which may be understood from the following Table 4, and from Fig. 1, Plate 122. Except in two instances, where the teeth were cast upon the felks or segments of the fly-wheel, the spur rims of all these wheels were made in segments, generally machine-moulded, which were secured upon the outer circumference of the felks by dove-tails, keys, and bolts, somewhat as shown in Fig. 1; the felks and spur segments in most cases were turned and bored to fit each other. It will be seen that, except in the first instance, the power transmitted was 1,000 I.H.P. or more; the speed at the pitch line was over 2,200 feet per minute; and the teeth in the pinion were few in number, of great breadth.

TABLE 4.—*Spur Gearing.*

Nineteen Segmental-Rim Wheels driving Pinions.

Power transmitted.	Circumferential Speed. Feet per minute.	Mean Pressure on Teeth.	Pitch of Teeth.	Breadth of Teeth.	Number of Teeth in Pinion.	Velocity Ratio, or ratio of Revs. of Pinion and Wheel.
I.H.P.	Feet.	Lbs.	Inches.	Inches.	Number.	Ratio.
700	2280	10,100	4·5	14	42	3·8
1000	2356	14,000	5·4	17	41	3·4
1000	2334	14,200	5·0	18	43	3·2
1000	2261	14,600	5·5	18	41	3·3
1000	2241	14,700	5·6	18	46	2·5
1000	2208	14,950	5·0	18	47	3·2
1000	2200	15,000	5·62	18	46	3·4
1080	2318	15,400	5·25	16¾	43	3·0
1100	2401	15,000	5·0	17	47	2·9
1100	2406	15,100	5·5	18	50	2·3
1100	2410	15,050	5·0	17	47	2·9
1130	2242	16,600	5·8	18	43	3·1
1150	2320	16,300	5·75	18	46	3·1
1150	2320	16,350	5·75	18	47	3·0
1190	2323	16,900	5·7	18	47	3·0
1200	2209	17,900	5·0	19	52	3·0
1200	2418	16,400	4·75	19	52	3·2
1220	2209	18,200	5·0	18¾	49	3·2
1360	2325	19,300	4·5	18	71	2·8

Moreover in many cases the pinion teeth were made of such a shape as to have a longer contact with the wheel teeth before than after passing the pitch point. All these wheels failed in one of two ways. Either the teeth were fractured as shown at *a a a* by excessive pressure on their ends, owing to the crank-shafts shifting in their bearings or getting out of level; or else the bearing of the segments upon the felks and against each other was ground away by jar, and the segments broke across, generally between the end tooth and the end but one, as at *c*. It is not possible to describe in detail the causes of this destructive jar, or the symptoms by which it may be detected; it is preferable to avoid entirely the use of wheels of this design under the conditions of large power and high velocity-ratio. If it be absolutely necessary to use gearing under these conditions, the spur segments should be carried upon the arms of the fly-wheel, as shown in Figs. 2 and 3, Plate 122, and not upon the felks; and the latter should have as large a radius as can be got in between the crank-shaft and the second-motion shaft, so that the power of the wheel may be as great as possible. To place the spur rim, whose velocity should be low, on the outside of the fly-wheel, whose velocity should be high, is contrary to common sense. The number of teeth in the pinion should approach sixty; and in order to obtain sufficient strength with the fine pitch which the division of the circumference of the pinion into as many as sixty parts will frequently require, the spur rim and pinion should be of steel. Contact should commence about half a pitch before the pitch point, and should cease about a pitch beyond, so that the work may be done rather in going out of gear than in coming into gear. This means that the bearing of the teeth upon each other should extend but little on each side of the pitch line: in other words, that the teeth should be short. In no case should their height exceed half the pitch. In some cases even shorter teeth may be desirable, in order to gain strength and to diminish wear; for when wheels differ much in diameter, the sliding of the teeth upon each other increases rapidly as their line of contact recedes from the pitch line. Short teeth may be narrower than longer teeth, and thus will be less likely to suffer from concentration of the pressure on their ends. It is also a good plan in moulding the teeth to bevel the wearing faces of the teeth of both wheel and pinion at the ends which are at the bottom of the mould: so that, when the wheels are geared together, with the bottom face of one wheel opposite the top face of the other, the bevelled faces of the wheel teeth will be at the right or left-hand end and those of the pinion teeth at the left or right-hand end, thus preventing concentration of pressure upon the extreme ends of either. This is a better plan than bevelling the ends of the teeth. When the number of teeth in the pinion has to be reduced to forty or less, double helical gearing should be used; but in this case the length of the second-motion shaft which carries the pinion should be short; and the shaft should have a claw coupling at each end, in order to allow the pinion to move from side to side, so as to distribute the load equally upon each half of the double tooth. Finally the pedestals for the second-motion shaft, and the fixings which carry them, must be massive and rigid. It is well to use wood keys behind these pedestals, in order to allow the wheels to separate, should anything get between them.

The sixteen breakdowns in group C are attributed to causes similar to the last; but with this difference, that the more serious evils of heavy load and high velocity-ratio were not both of them present. By keeping the shafts level, and the points and roots of the teeth chipped, most of these breakdowns might have been prevented. Many steam-users are quite satisfied to see a pair of wheels with teeth polished from point to root, considering they have reached perfection. This is all very well, so long as the crank-shaft can be held quite steady; but let an accident occur, such as a hot neck or anything which will displace the wheels by ever so little, and the result is sure to be disastrous.

In group D, containing breakages from high speed and irregular pitch, ten out of the eleven wheels had spur segments moulded from patterns, instead of by machinery; and in three of the ten the teeth were cast upon the felks, and were twisted and drawn, as they generally are when cast in this way, by the contraction of the mass of metal of which they form a part. In every instance the speed was high, and in several cases there was more or less backlash or over-running.

Out of the ten breakdowns in group E, caused by bolts or broken teeth getting between the wheels, six were caused by bolts used for fastening spur segments. In each instance the bolt passed through the segment between the teeth, its head being countersunk; and it was secured by a nut on the inner side of the felk or bracket to which the segment was attached. The bolts broke at the screw threads, and the shanks, having nothing to hold them back, were driven out by centrifugal force. Few wheels have segments fastened in this way, but among the few there were these six breakdowns.

Of the seven wheels in group G which broke from internal stress, six were cast whole, of the following diameters:—6 ft., 6 ft. 10 ins., 8 ft. 2 ins., 9 ft. 8 ins., 10 ft., and 10 ft. 11 ins.; and one of 10 ft. 9 ins. diameter was cast in halves. When large wheels are cast whole, the bosses should be split at least between each pair of arms, slotted out, and packed with planed wrought-iron plates, the whole being afterwards secured by strong wrought-iron hoops shrunk on each end of the boss. A key should be fitted under each segment of the boss.

In the five instances in group K, in which the breakages have been attributed to the small size of the pinions, the numbers of teeth in the pinions were 29, 32, 34, 34, and 36. It is of course possible to make wheels mathematically correct with less than half these numbers of teeth; but where one of the shafts is movable, like the crank-shaft of an engine, pinions with so few teeth cannot be used to transmit much power, except at speeds unsuitable for mill work. Such wheels should have double helical teeth, as already described.

Air-Pump Motions.—The 121 breakdowns of these parts may be subdivided as in Table 5.

The breakages of air-pump motions are almost as difficult to treat as those of valve-gear. There is the same uncertainty as to stresses, and the same absence of detailed information as to the dimensions of the broken parts and as to the circumstances under which the breakdowns occurred. The consequence is that nearly half the cases have been included in group A under the heading "weakness, wear and tear, or neglect." At first sight it might appear that there

TABLE 5.—*Air-Pump Motions.*

Cause or nature of Breakage, and Number of cases.

A Weakness, wear and tear, or neglect:—		
Air-pump-rod cross-heads broken	20	
Levers, principally bell-crank, broken	17	
Crank-shafts, cranks, rocking shafts, or eccentrics, broken .	11	
Slides or slide-bars, broken	3	51
B Air-pump rods broken:—		
At cotter holes by driving cotters, or from weakness at other parts	15	
From various causes	6	21
C Fastenings getting loose:—		
Cotters coming out of top ends of bucket-rods	7	
„ „ „ other parts of motions	4	
Bolts breaking or getting loose	7	18
D Breakages of eye-bolts or rod-ends at bottom of trunks, from wear		14
E Fastenings at bottom ends of bucket-rods, getting loose or breaking		12
F Sundry breakages		5
Total breakdowns of Air-Pump Motions . .		121

should be no difficulty in distinguishing between the effects of these three causes; in fact it is otherwise. The load on an air-pump bucket when the head valve opens may be anything from 10 to 20 lbs. per square inch; for the first a motion may be sufficient, for the second far too weak. Again, with the arrangement of links, bell-crank levers and side-rods, commonly adopted for horizontal engines—and forty-six out of the fifty-one motions in group A were of this kind—the distribution of the load upon the different parts may be materially affected by improper adjustment of brasses and cotters; yet all evidence of the fact may be destroyed on the occurrence of a breakdown.

As regards the cross-heads, the author has sufficient data to say that they were generally too weak. In the example shown in Fig. 4, Plate 122, the bucket was 24 inches diameter; assuming the load upon it to have been 15 lbs. per square inch, and this load to have been equally distributed upon the two side-rods, the bending stress at the neck of the journal where fracture occurred would have been 15,750 lbs. per square inch. It is not surprising that the cross-head broke as it did, after 49 million applications of this stress.

As regards the other parts mentioned in group A, there is not enough information to decide which of the three causes—weakness, wear and tear, or neglect—was most destructive. All that can be said about them is that they afford strong evidence that many air-pump motions are unable to correspond with their environment. They need more attention than they commonly receive, greater strength, larger bearings, cleaner and lighter situations. One reason why they are so often neglected is that they often cannot be approached with safety while at work, and only at the expense of a suit of clothes while standing. For factory engines, where weight is of little consequence, the parts should be calculated to bear a load of 20 lbs. per square inch upon the bucket with a stress of say 5,000 lbs. per square inch; and the wide cross-heads with side-rods far apart, so common in horizontal engines, should if possible be done away with.

The second group B is important, because cotters are here met with for the first time. It contains fifteen instances of rods broken at the cotter-hole. Cotters are often treated with slight consideration. This is unwise, because a little inattention will change a cotter from a useful servant into an effective instrument of destruction. For instance, if, as in Fig. 5, Plate 123, a cotter have not exactly the same taper as the cotter-hole, the stress will be concentrated on the metal at the edge of the cotter-hole where the material runs up to a sharp edge, as shown at *a a* in Fig. 6. Again, if the cotter be not deep enough to be absolutely free from any tendency to bend, the same concentration of stress upon the extreme edges of the cross section will occur, as shown in Fig. 7. And even if the cotter be absolutely rigid and accurately fitted, the stress at the edges of the cotter-hole may be much enhanced if the rod be permitted to bend in the plane in which the cotter is driven, as shown exaggerated in Fig. 8. A cotter should therefore be deep enough to be rigid, and should be accurately fitted; the cotter-hole should be formed with all its edges well rounded off, as indicated in Figs. 9 and 10, so as to increase the quantity of metal available for bearing the maximum stress; and lastly, the cotter should be driven in the plane at right angles to that in which bending of the rod is likely to occur, as indicated in Fig. 11, so that the cotter-hole being in the neutral position may not suffer deformation. The sketches are of course exaggerated; but it is sometimes useful, in designing pieces of machinery, to consider what would happen if the material were capable of being stretched and deformed like india-rubber.

Cotters occur also in the third group C; and it is worth noting that six of the first seven breakdowns in this group were caused by cotters coming out of the top ends of air-pump bucket-rods of beam engines. The air-pump connecting-rods of these engines, being long and slender, often vibrate or whip considerably; hence it is easy to see that, if the cotters connecting them to the bucket-rods be driven in the manner shown in Fig. 8, Plate 123, they are likely to get loose.

The fourth group D is more satisfactory to deal with, as it teaches a definite lesson. Among the engines which have furnished the material for this paper there were certainly not many more than fourteen which had air-pump buckets driven by trunk motions, possibly not even so many as fourteen; so that the figure in Table 5 shows that, if the trunk motions insured did not all of them break down, at least a large percentage of them did, and some of them more than once. The cause was the same in every instance:—accumulation of dirt in the bottom of the trunk; wear of the pin connecting the rod to the eye-bolt, or of the eyes in which the pin worked; heavy knocking; and breakage. The lesson taught is that trunk motions should not be adopted, if there be room for any other arrangement.

The fifth group E is also satisfactory, as showing clearly what should not be done in the matter of fastening air-pump buckets upon their rods. In all the twelve instances the buckets were slipped upon the ends of the rods, and secured against a cone or collar by nuts or cotters or both on the underside. Thus the fastenings could not be examined without drawing the buckets, and were neglected till they got loose or broke or disappeared by corrosion, with the result that the buckets dropped off the rods, and were pounded to pieces by the rod ends. The collar or the big end of the cone should be at the extreme end of the rod, and the bucket should be secured against it by a cotter, or preferably by a nut, on the upper side; the same cotter or nut may also secure the guard, if the bucket have a single valve. Or if plain cast-iron buckets be used, they may be warmed and screwed firmly upon the ends of the rods, which may then be riveted over.

Air-Pump Buckets and Valves.—Here both the causes of damage and the precautions to be taken for avoiding them appear more clearly than in the previous classes. The eighty-eight cases may be subdivided as under:—

TABLE 6.—*Air-Pump Buckets and Valves.*

Cause or nature of Breakage, and Number of cases.

A	Foot-valves breaking, including frames, valves, guards, and fastenings	32
B	Buckets jammed by worn packing-rings	21
C	Head-valves breaking	15
D	Bucket-valves and guards breaking	10
E	Buckets breaking	8
F	Miscellaneous	2
	Total breakdowns of Air-Pump Buckets and Valves	88

Of the foot-valves which caused the thirty-two breakdowns in the first group A, all but one were the flap-valves of ordinary vertical single-acting air-pumps. When they were of brass, either the frames were broken by the hammering of the valves upon them; or the valves got loose, owing to the wearing away and breakage of the hinge-pins at the ends, or of the eyes in which these pins were held. The broken or liberated pieces were then washed into the pump, and getting on end during the up stroke of the bucket smashed the latter when it descended, or else drove out the air-pump bottom. When the valves were of india-rubber, their guards either broke, or got loose through the breakage of the bolts which fastened them to the grids; or else the grids themselves got loose. If the grid were strongly made, as shown in Figs. 12 and 13, Plate 123, and fitted into grooves in the air-pump bottom, if the valve were made of india-rubber and hung upon pegs *p* screwed into the grid, and if the whole were secured in place by the foot valve-box lid *l* with guard cast upon it, a fruitful cause of breakdown would be removed. If the quantity of oil in the condensed steam be so great as to prevent the use of india-rubber, as is sometimes the case with surface-condensers, then it is best to use a number of small brass valves in the bottom of the barrel: supporting if necessary, by a foot in the middle, the grid in which they are fixed; and providing a door in the side of the barrel for facilitating examination. Such valves, if they get loose, are too small to do damage.

Of the breakdowns in the second group B, three were due to the swelling of wood lagging on buckets, whereby the buckets were fixed so tightly in the barrels that the rods were torn out of them or the motion was broken. The remainder were caused by brass packing-rings, which having worn thin had broken, and jammed the buckets in the barrels. Such rings are expensive, dangerous, and entirely useless. It is not necessary that the bucket of a vertical or properly constructed horizontal air-pump should be absolutely water-tight. With moderately clean water a plain bucket, without any packing whatever, will maintain as good a vacuum as one with the most expensive packing. If the water be gritty, a bucket packed with rope is best.

The breakages of head-valves in group C, or more correctly of grids on which head-valves worked, were generally due to weakness. These grids are often little more than flat discs, with about 30 per cent. of their area removed to form the water-ways. They should be well strengthened by radial ribs; and these, as well as the bars between the water-ways, should be tapered to an edge on the underside, so as to offer little resistance to the water when it strikes them.

Five of the breakdowns in group D were caused by the breakage of air-pump bucket-valve guards; four by the breakage of bolts securing guards, or securing the hinges for brass valves; and one by the breakage of a brass valve. To give an idea of the extent of the damage which sometimes follows a small breakage, it may be mentioned that the breakage of one of these bolts bent the air-pump rod and piston-rod, and broke the cross-head and slide-bars; a piece of one of the latter fell into the crank pit, and the crank, coming into contact with it, lifted the shaft, broke the pedestal and bed-plate and holding-down bolts and also the boss and one arm of the fly-wheel, besides several of the spur segments attached to the fly-wheel arms.

Of the eight buckets in group E, five failed through fracture of the arms connecting the rim to the central boss, either from weakness or from undue initial stress. The three others failed from various causes.

Columns, Entablatures, Bedplates, and Pedestals.—The eighty-six breakdowns under these heads are divisible into the following groups:—

TABLE 7.—*Columns, Entablatures, Bedplates, and Pedestals.*

Cause or nature of Breakage, and Number of cases.

A	Settlement of foundations:—		
	Crank-pedestals and bedplates of beam engines	14	
	Entablatures of ditto	6	
	Columns of ditto	5	
	Bedplates of horizontal engines, near crank pedestals	12	37
B	Water in cylinders:—		
	Crank pedestal of beam engine	1	
	Crank pedestal cap of ditto	1	
	Beam pedestal of ditto	1	
	Column	1	
	Bedplates of horizontal engines	7	
	Crank pedestal of ditto	1	12
C	Weakness:—		
	Pedestals or caps of beam engines	5	
	,, ,, ,, horizontal engines	2	7
D	Hot necks:—		
	Crank pedestals or caps		5
E	Causes not ascertained:—		
	Columns	2	
	Entablature	1	
	Crank and beam pedestals and caps	15	18
F	Miscellaneous		7
	Total breakdowns of Columns, Entablatures, Bedplates, and Pedestals		86

In this class, as in the last preceding, the causes of many of the breakdowns are well defined. Of the total of eighty-six breakdowns, the thirty-seven in group A—namely twenty-five of beam engines and twelve of horizontal engines—were caused by settlement of the seats on which the engines stood, either by sinking or softening of the ground below, or by softening of the stones and destruction of the cement or mortar in the joints by oil. The settlement of column and cylinder seats is generally due to the first of these causes; that of the walls under crank pedestals to the second. When column seats settle, the holding-down bolts of the columns should be slackened and the beam hung up, so that the entablature relieved of weight may take its natural position. The columns should then be packed up with broad folding wedges. If the seat be too light or the stones broken, it is sometimes best to put in an entablature of sufficient depth to carry the beam without the support of the columns, tying the new entablature down at each end to beams let into the bottom of the walls. Most of the breakages of columns and entablatures are caused by tightening the holding-down bolts when the column seats have gone down. The bedplates of horizontal engines also are often broken in this way. The bedplates under the crank pedestals of beam engines, being merely thin slabs of metal, are frequently broken by the mere pressure on the crank pedestal when the stone below has sunk. In such cases the only radical cure is to rebuild the seat, or to replace the upper part of it by a strong deep casting, capable of sustaining the greatest weight which can come upon it if supported only at the ends. The best way however is to keep the seat, and the ground below it, dry and free from oil. In the case of concrete seats this is especially necessary, as oil soon converts the concrete into a paste. When concrete is used, the safest plan is to cover the upper surface with strong cast-iron plating, having raised edges to retain all oil and water, and planed facings to receive the cylinders and bedplate. In all cases arrangements should be made for catching the oil from the bearings, and conveying it to a suitable receptacle.

The twelve breakdowns in the second group B were caused by water in the cylinder. In some instances the water came through the condenser, in others from the steam pipes. When an engine is stopped hurriedly, either by the runaway motion or by hand, it often happens that the usual precaution of destroying the vacuum is neglected, and the water from the cooling pond is forced up the exhaust pipe and fills the cylinder, causing a smash when the engine is re-started. When the water comes from the steam pipes, it is generally at starting time. Lancashire boilers seldom prime; but if the steam pipes be long and badly laid, much water may accumulate in them while the engine is standing, which will be driven into the cylinder when the engine begins to move. The preventive in the first case is an air valve connected to the runaway valve and stop valve; and in the second a separator, if possible close to the engine, but at any rate at the lowest point of the steam pipes. The steam pipe ought to have a continuous fall from the junction valve on the boiler to some point near the engine, where it should then turn downwards into a separator, as shown in Fig. 14, Plate 123. From the separator the steam pipe should rise continuously to the engine, the stop valve being placed as near the highest point as possible. The separator should be drained by a steam trap, and should also have an open drain-cock and a water gauge. Usually the author has made the cross sectional area of the separator such that the velocity of the steam may not exceed 5 feet per second; but judging from experiments made in America* a much smaller area would be sufficient. If a separator be considered too expensive, a plain well-pipe will suffice to prevent damage. Spring-loaded safety-valves on the cylinders are great safe-guards; but they do not prevent breakdown if the quantity of water be large.

For the remaining cases in groups C, D, E, F, no general remedy can be prescribed.

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* "Reliability of Throttling Calorimeters," by Professor James E. Denton. *Engineering*, 14 Feb. 1896, page 207. A velocity of 17 feet per second in a Stratton separator is said to have given steam with less than 1 per cent. of moisture.

Main Shafts.—Of these there are forty-nine instances, which may be subdivided as under:—

TABLE 8.—*Main Shafts.*

Cause or nature of Breakage, and Number of cases.

	Breakages of Plain shafts:—		
A	Wear and tear:—		
	Fractured in neck	37	
	„ in body	3	40
B	Bearings out of line		4
C	Cause not ascertained		1
D	Internal stress		1
	Breakages of Cranked shafts:—		
E	Wear and tear		2
F	Water in cylinder		1
	Total breakdowns of Main Shafts		49

It is now generally admitted by engineers that iron and steel do degenerate by wear and tear, and that such parts of steam engines as the main shafts break down in old age under loads which they supported easily in their youth. All the forty main shafts in group A seem to have failed from this cause, some sooner, some later, according to the hardness of their lives and the soundness of their constitutions. In the first thirty-seven cases, where the fracture occurred in the neck, the process of destruction was generally gradual; the symptoms of weakness, namely black or reedy marks or slight surface-cracks, usually presented themselves several years, sometimes many years, before the final breakdown of the shaft; but occasionally the life of an apparently perfectly sound shaft was cut short suddenly. An example of gradual destruction, from the appearance of the first well-defined crack to dangerous fracture, is shown in Figs. 15 to 15*d*, Plate 124, which represent the state of the shaft at intervals of twelve months from 1888 to 1892. An example of the development of a dangerous crack within a period of six months is shown in Fig. 29. The following Table 9 (pages 556–7) gives approximately the loads under which these shafts worked during their later years, and the number of revolutions made before breaking. The direction and extent of the fractures are shown in Figs. 15 to 51, Plates 124 and 125, to which the numbers in the first column refer.

TABLE 9 (*continued on opposite page*).

Thirty-seven Plain Main Shafts fractured in neck by wear and tear.

See Plates 124 and 125.	Description of Engine.	Material of Shaft.	Mean Piston-Speed. Feet per minute.	Maximum Bending Stress, crank on centre. Per sq. in.	Equivalent of maximum Bending and Twisting Stress combined. Per. sq. in.
Fig.	*See foot-notes.*		Feet.	Lbs.	Lbs.
15*d*	2 McN B	W I	374		13,130
16	2 McN B	W I	352		11,410
17	2 McN B	W I	360		8,230 9,240
18	2 McN B	W I	330		5,740
19	2 McN B	W I	340		10,570
20	2 McN B	B S	396		5,290 6,370
21	2 B	W I	350		7,890 13,180
22	2 B	C I	408		5,960
23	McN B	C I	384		5,200
24	McN B	W I	430		12,400
25	McN B	W I	315		10,700
26	McN B	B S	425		10,280 12,600
27	McN B	W I	420		8,570
28	McN B	W I	390		12,800
29	McN B	W I	384		5,900
30	McN B	W I	468		9,660
31 31*a*	McN B	W I	444		10,080
32	McN B	W I	450		9,920
33	McN B	Wh S	450		14,420
34	B	W I	380		4,205
35	B	W I	324		8,400
36	2 H T	W I	492	3,880 5,550	5,760 7,730
37	2 H T	W I	500	5,760	8,000
38	2 H T	B S	378	6,560	10,300
39	2 H T	W I	492	7,080	8,040
40	2 H T	W I	408	4,500	7,120
41	2 H	B S	440	6,900	9,980
42	2 H	W I	350	6,770	8,770
43	2 V	W I	350	8,590	8,490
44	2 V	W I	376	7,600	11,900
45	H T	S	730	4,730	8,940
46	H T	W I	492	5,370	9,190
47	H T	W I	730	4,250	6,460
48	H	W I	432	6,500	7,340
49	H	W I	445	8,900	11,600
50	H	W I	295	9,600	10,400
51	H	W I	350	15,100	15,000

McN B = McNaughted Beam engine; 2 McN B = Pair of McN B.
H T = Horizontal Tandem engine; 2 H T = Pair of H T.
H = Horizontal single-cylinder engine; 2 H = Pair of H side by side.
B = Beam engine. 2 V = Pair of Vertical engines.

(*concluded from opposite page*) TABLE 9.

Thirty-seven Plain Main Shafts fractured in neck by wear and tear.

See Plates 124 and 125.	Millions of Revolutions.	Remarks.
Fig.	Millions.	
15*d*	123	
16	149	Shaft said to have made 149 million revs. under this stress; but query?
17	102	Load gradually increasing.
18	451	Well authenticated instance of wear and tear.
19	88½	Revs. were more than 88½ millions; but how many more, or under what load, could not be ascertained.
20	44½	
21	102	Load gradually increasing.
22	177	
23	698	Engine has made about 698 million revs., and there is no record of a new shaft having been put in. Probably load was much less at first.
24		
25		
26	79 3	After 79 million revs., pressure was raised and load increased; after which the shaft made 3 million revs. more.
27	186½	At least 186½ million revs.; may have been more.
28	38	
29	52	
30	123	No fillet at end of neck.
31 31*a*	46	
32	130½	
33	41½	
34		No sketch made of fracture at time of breakdown.
35		No fillet at end of neck.
36	62 27	After 62 million revs., larger high-pressure cylinders were put in, and load was increased.
37	71½	
38	36½	
39	124	
40	109½	
41	101	
42	176	
43	311	Not quite certain whether revs. may have been fewer.
44	181	Doubtful whether stresses always as heavy as here given.
45	24½	
46	138	
47		
48	236	Load was less in early life of shaft.
49	31	
50	185	Load irregular; maximum stress sometimes 12,000 lbs. per sq. inch, but often very small indeed.
51	134	

C I = Cast-Iron; W I = Wrought-Iron.
S = Steel, probably Siemens-Martin.
B S = Bessemer Steel.
Wh S = Whitworth fluid-compressed Steel.

In calculating the stresses on the shafts of horizontal and vertical engines, the effect of the inertia of the moving parts has been estimated and allowed for; and Table 9 shows both the bending stress when the crank was on the centre, and also the stress produced by a bending moment equivalent to the combination of the actual bending and twisting moments, when this equivalent moment was a maximum, generally at about the point of cut-off. In the case of beam engines, the correction for inertia has not been made, and only the stresses due to the combination of the bending and twisting moments are given. Although uncorrected, these stresses will be approximately correct, because the maximum stress in most cases occurred near the middle of the stroke, where the effect of inertia would be small; the actual stresses would probably not be more than 10 to 15 per cent. less than the amounts given in Table 9.

The equivalents of the bending and twisting moments are calculated by the usual formula, $M = \frac{1}{2} M_b + \frac{1}{2} \sqrt{M_b^2 + M_t^2}$, on the assumption that the pressure was applied at the middle of the crank-pin, and that the shaft was supported at the middle of the bearing. The weight of the fly-wheel has not been taken into account. This weight does not affect the calculated stress at the middle of the neck; but it increases the stress at the end next the wheel, as shown by the diagrams, Figs. 54*a* to 54*d* and 55*c* to 55*f*, Plates 127 and 128. For this reason, and also because it is quite certain that when an engine is at work the resultant reaction of the main bearing does not act through the middle of the neck, as it is supposed in text-books to do, the amounts given in Table 9 cannot be considered as more than approximations to the actual stresses.

The three shafts in group A which fractured in the body are shown in Figs. 52, 52*a*, 53, and 54, Plates 126 and 127. In the first, the cracks appeared as shown in Fig. 52, close to the collar, and gradually extended till they attained the dimensions shown in Fig. 52*a*, when the shaft was taken out and broken under a tup; they were distinctly due to bending stresses. In the second, the crack was found under one of the eccentrics, close to the swell for the fly-wheel keys, as shown in Fig. 53, Plate 126. The engine was a McNaughted beam engine, and had made altogether 176 million revolutions; originally it had been a simple beam engine, but after making 82 millions it had been McNaughted, and may at the same time have had a new shaft. Since then the shaft had made 94 million revolutions under a stress varying from ± 1,250 lbs. to ∓ 9,900 lbs. per square inch in each revolution. The third shaft, shown in Fig. 54, Plate 127, broke in the swell for the fly-wheel keys after running 80½ million revolutions under stresses varying from ± 2,500 lbs. to ∓ 8,200 lbs. per square inch in each revolution. The bending moments in four positions of the cranks are shown in the diagrams, Figs. 54*a* to 54*d*.

In undertaking this laborious investigation, the writer hoped that some connection between stress and durability would have been disclosed. In this he has been disappointed; nevertheless he gives figures as facts not usually recorded.

Of group B in Table 8 it is unnecessary to write; but the single case in group C is too remarkable to be passed by unnoticed. The shaft, shown in Fig. 55, Plate 128, coupled a pair of McNaughted beam engines, and carried a spur fly-wheel. On removing one of the eccentrics for the purpose of making some alterations, a deep circumferential groove was found, as shown in Figs. 55*a* and 55*b*, Plate 126. It varied from ⅝ inch to 1 inch in depth, and from ⅛ inch to ¼ inch in width at the surface. The shaft was of wrought-iron, and had worked night and day except on Sundays for 27 years, during which it had made about 340 million revolutions. When broken, the interior was found to be quite sound. The bending moments in four positions of the cranks are indicated by the diagrams, Figs. 55*c* to 55*f*, Plate 128. The maximum stress varied from ± 7,200 lbs. to ∓ 10,180 lbs. per square inch on the original section, or from ± 11,700 lbs. to ∓ 16,400 lbs. per square inch on the section remaining inside the groove. The fly-wheel and eccentric were both of cast-iron, held by wrought-iron keys. What was the cause of the grooving?

The single case in group D, Table 8, should also be noticed. The shaft was of Whitworth fluid-compressed steel, and broke after running 61½ million revolutions under the low stress of only about 4,600 lbs. per square inch. The crack, which is shown in Fig. 56, Plate 126, had clearly started from the inside, and gradually extended outwards. It is therefore attributed to internal stress.

The remaining instances in groups E and F need no remark.

Connecting Rods.—The forty-one cases may be subdivided as under:—

TABLE 10.—*Connecting Rods.*

	Cause or nature of Breakage, and Number of cases.	
A	Breakage of gibs or cotters for securing open-ended straps; at big ends 10, at little ends 6	16
B	Breakages of open-ended straps; at big ends 11, at little ends 2	13
C	Forked ends; wrought-iron rods 5, cast-iron rod 1	6
D	Big ends of cast-iron rods	2
E	Closed wrought-iron links at top ends of cast-iron rods	2
F	Bolt in marine-pattern end broken at thread	1
G	Imperfect weld in body of wrought-iron rod	1
	Total breakdowns of Connecting Rods	41

The subdivision brings out the fact that of forty-one breakdowns, most of which were complete smashes, no less than twenty-nine were brought about by the failures of open-ended straps, or of the gibs or cotters for securing them. The failures were generally due to weakness. The practice seems to be to proportion gibs and cotters as if they could fail only by shearing. As a matter of fact they generally fail much more like a girder, by bending; and considered as uniformly loaded girders they are often far too weak. The opening of the straps, which always takes place to a greater or less extent, also tends to break off the jaws of the gibs. The straps in most cases gave way at the oil holes, or in the flat part between the cotter hole and the bend, not in the middle of the bend itself; and they failed under comparatively low calculated stresses. The cracks moreover generally commenced on the inside, where they could not be seen while the straps were in place. If open straps be used, they ought to be secured by strong bolts, in addition to the gibs; or by bolts alone, as in locomotives. But the better plan is to use solid ends, wherever possible; and it always is possible when the crank-pin is overhung.

As regards the breakages of forked ends in group C, it may be suggested that if forked ends be used it is best to fix the centre-pin, about which the rod swings, in the forked end of the rod itself; and to let the pin work in the cross-head, instead of in the forked end of the rod: only in this way can equal distribution of stress upon the two arms of the fork be insured.

Cylinders and Valve-Chests.—In all thirty-five cases, divisible as under:—

TABLE 11.—*Cylinders and Valve-Chests.*

Cause or nature of Breakage, and Number of cases.

A	Fractures from weakness:—		
	Flat surfaces in valve-chests	9	
	Cylinder covers	6	
	Valve-chest doors	3	18
B	Cylinders broken by water		5
C	„ „ by excessive pressure		3
D	„ „ by corrosion		2
E	Cylinder feet broken off		4
F	Liner cracked by unequal expansion		1
G	Throttle-valve casings broken by water-hammer action		2
	Total breakdowns of Cylinders and Valve-Chests		35

Of the nine fractures of flat surfaces in group A, six occurred in the flat surfaces of slide-valve chests or of the passages in connection with them; and three in flat-sided passages connecting the two steam valve-boxes of Corliss cylinders, in which the cylinder valve-boxes and passages were contained in a single casting. One of the Corliss cylinders was the condensing cylinder of a compound engine; all the others were high-pressure cylinders. Of the cylinder covers, two belonged to condensing cylinders, the rest to high-pressure. All the valve-chest doors belonged to high-pressure cylinders. All these breakages may be ascribed to weakness, that is, inability to bear the ordinary working pressures and stresses induced by unequal expansion of the different parts; and besides the fractures mentioned in Table 11 there were a considerable number due to this same cause, which were not of sufficient extent to be classed as breakdowns.

To cast large cylinders in one piece with their valve-chests and passages is in the writer's opinion entirely wrong, unless it be important to keep down weight.

The next group B contains breakages from water. In one instance the cylinder had safety-valves; in the others there were none. Safety-valves are no doubt a safe-guard; but they are far from sufficient to avert disaster, if large quantities of water get into a cylinder. An air-valve on the condenser or exhaust pipe, connected with the stop-valve, and a separator or well-pipe, as described previously (page 554), are the proper preventives.

Of the three breakages C from excessive pressure, all of which occurred in the low-pressure cylinders of compound engines, one was due to deliberate overloading during the repairs of another engine; the other two were the results of accidents. In both of the latter the slide-valve of the low-pressure cylinder had stuck fast at the middle of its travel, owing to the eccentric having slipped, and had blocked the ports into the cylinder. The engine had been kept running by the high-pressure cylinder and a heavy rope-drum; and the steam having no outlet had accumulated in the low-pressure valve-chest till the latter burst. Other similar accidents have occurred. All prove the necessity of having a large safety-valve on the pipe between the high and low-pressure cylinders of every compound engine.

Of the remaining instances it need only be said that the cylinder feet in group E were broken by excessive compression, weakness, or tightening the holding-down bolts.

Parallel Motions.—Of the thirty-five breakages twenty-five were breakages of eye-shafts, through weakness and abrupt change of section from square to round; six were breakages of radius rods; and four of radius-rod brackets. One of these last brought the whole engine to the ground; the other cases had no serious consequences. Eye-shafts should be made much stronger than they usually are; but it is not worth while saying much about them, as it is not likely that many more will be made, except to replace breakages.

Governors and Governor Gear.—In all twenty-eight cases, of which several led to racing, with disastrous consequences. They may be divided thus:—

TABLE 12.—*Governors and Governor Gear.*

	Cause or nature of Breakage, and Number of cases.	
A	Governors broken: arms 5, pins and bolts 4, spindles 3, lever 1	13
B	Driving gear broken: spur and bevel wheels 9, shafts 2	11
C	Connections to valve gear damaged: throttle-valve spindles 2, runaway gear 2	4
	Total breakdowns of Governors and Governor Gear	28

It is difficult to prescribe for breakages of this class. All that can be said is that the governor should be driven from the crankshaft either by gearing or by three ropes; that it and its connections should be carefully examined daily; and that it should have an efficient runaway-motion attached, which will come into action not only when the balls rise too high, but also when they fall to the bottom, so that it may shut off steam in the event of the governor ceasing to revolve through breakage of the driving gear.

Piston-Rods.—The twenty-seven cases may be grouped as under:—

TABLE 13.—*Piston-Rods.*

	Cause or nature of Breakage, and Number of cases.		
	Rods broken at Cross-head end:—		
A	Rods broken at cotter holes		15
B	Cotters broken or loosened:—		
	broken by wear or weakness	2	
	„ „ water in cylinder	2	
	got loose and came out	2	6
C	Screw-thread stripped		1
	Rods broken at Piston end:—		
D	Screwed ends broken off		2
E	Rod broken at cotter hole through corrosion		1
	Rods broken in body:—		
F	Cause not ascertained		2
	Total breakdowns of Piston-Rods		27

The particulars of the fifteen cases in group A are given in the following Table 14, and in Figs. 57 to 71, Plate 129. The cross section annexed to each figure is intended to indicate the plane in which the cotter was driven: when it was driven in the plane in which the crank-pin revolved, the cotter hole is shown vertical; when in the plane perpendicular to this, horizontal:—

TABLE 14.

Fifteen Piston-Rods broken at cotter hole in cross-head end.

See Plate 129.	Load per square inch.	Millions of Revolutions.	Material of Rod; and Remarks.
Fig.	Lbs.	Millions.	
57	5,900	111	Wrought-iron.
58	11,000	44	Wrought-iron.
59	6,600	117	Wrought-iron.
60	8,000	46	Steel, probably Siemens-Martin.
61	5,300	104	Bessemer steel.
62	5,300	138	Wrought-iron.
63	8,500	3½	Wrought-iron. Cotter had been repeatedly drawn and driven up, owing to trouble with piston.
64	2,100 3,100	59 59	Wrought-iron. Stress only 2,100 lbs. per sq. inch for first 59 million revs.
65	2,600		Wrought-iron.
66	4,360		Wrought-iron.
67	6,550	247	Wrought-iron. Load probably lighter in early life.
68	5,100	68	Wrought-iron.
69	3,900	25	Wrought-iron. End of rod was not sound.
70	4,700	144	Steel, probably Siemens-Martin.
71	4,600	88½	Steel, probably Siemens-Martin.

In calculating the stresses in this table, the weights of the pistons and piston-rods have been estimated, and the effects of their inertia allowed for. The stresses so arrived at are of course the mean stresses resulting from a uniform distribution of stress over the entire cross-section of the rod. Moreover they do not include the stresses produced by driving the cotters. Looking at the low intensities of the breaking stresses thus calculated, it becomes evident, either that the stresses produced by driving the cotters were very great, or else that the distribution of stress was very unequal. The majority of these rods the author has little doubt were broken by driving imperfectly fitted cotters; he has already explained his views (page 548) with respect to these dangerous articles. As regards the shape of the rod ends in which the cotter holes are bored, in factory engines, where weight is of little consequence, piston-rods are always reduced at the end that enters the cross-head. The reduction is generally made abruptly, as shown in Fig. 71; and until recently the end of the rod was generally tapered, and the cross-head drawn up by the cotter against the shoulder or taper. The abrupt change of section is a source of weakness, especially in steel. The author has in his possession a fine example of the effect of a shoulder barely 1–16th inch deep on a steel rod, which gave way at the change of section as cleanly as if it had been cut across. Also it is wrong to cotter against a shoulder or taper, because the rod end being free may be wedged off if the cotter be driven hard enough. The best plan is to make the end of the rod cylindrical, to let it butt against the bottom of the cross-head or socket, and to join it to the body of the rod by a gentle cone. The sharp edge of the socket should be taken off, like the sharp edge of a rivet hole. When the rod passes through the cross-head, it is best to use a nut. What the shape of the rod end should then be, the author is not prepared to say, having had too little experience of screwed ends to become acquainted with their peculiarities. Probably an acute cone, as shown in Fig. 72, Plate 129, followed by a cylinder of less diameter than the screw, will be found to answer best.

Piston-rod Cross-heads.—The twenty-seven examples may be grouped as under:—

TABLE 15.—*Piston-rod Cross-heads.*

Cause or nature of Breakage, and Number of cases.

A Weakness, or wear and tear:—		
Arms of cross-head broken	9	
Centres broken in sockets	6	15
B Accidents		4
C Sundry causes		8
Total breakdowns of Piston-rod Cross-heads . . .		27

As regards the first group A, it is not easy to separate the effects of wear and tear from those of weakness, because of the uncertainty about the distribution of the load upon the two arms of the cross-head, and about the effect of the more or less rapid change of sectional area where the fractures occurred. The best plan seems to be to give the calculated stresses on the assumption of equal distribution, and to leave every one to draw his own conclusions. These stresses are given in Table 16; and the cross-heads are shown in Figs. 73 to 87, Plates 130 to 132.

The process of destruction, whether under a light load as in Fig. 84, Plate 132, or under a heavy load as in Fig. 79, Plate 131, was generally the same: namely a crack commencing in beam engines at the top and bottom, and in horizontal engines at the back and front, of the weakest cross-section, and gradually eating its way inwards towards the neutral axis. This action is clearly shown by the cracks in Fig. 79, and by the cross section appended to Fig. 84.

In the second group B three of the breakages were caused by oil cups or bolts falling between the slide-blocks and the ends of the guides; and one by the end of the cross-head arm coming in contact with the rod of a disused pump which had been coupled to it.

Three of the breakages in group C started from cotter holes, as shown in Fig. 88, Plate 132, and appear to have been caused by the drifting action of the coned ends of the rods, for the stresses due to the bending moments did not exceed 3,000 lbs. per square inch. Another was caused by the breakage of a bolt, which had secured a cap like that at the big end of a marine-pattern connecting-rod. The remainder were fractures in the bodies of cross-heads, due most likely to flaws in the forgings.

Pistons.—Of the twenty-two breakdowns originating with pistons, ten were due to junk-ring or cover bolts getting loose or breaking; three to rings getting thin from wear and breaking; two decidedly to water in the cylinder; and seven to causes not ascertained. Breakages of bolts and rings can be prevented to a great extent by periodical examination. They have been far less frequent since mineral oil came into general use as a lubricator; but they still

TABLE 16.

Fifteen Piston-rod Cross-heads broken by weakness or wear and tear.

See Plates 130 to 132.	Maximum Stress per sq. inch.	Millions of Revolutions.	Remarks.
Fig.	Lbs.	Millions.	
73	5,400 6,400	117	During this period, stress increased from 5,400 lbs. to 6,400 lbs. per sq. inch. Cross-head possibly may have made 234 million double-strokes; but if so, the load upon it is unknown.
74	6,700 8,500	148 52½	After engine had made 148 million revs. the pressure was raised.
75	5,850 33,000	88½	Increase of stress was partly due to increase of load, and partly to vertical* diameter of journal being reduced by wear from 2 inches to $1\frac{3}{16}$ inch. * It was a beam engine.
76	8,800 11,800	73	Increase of stress due to gradual increase of load.
77	8,900 14,400	288	Load was very variable.
78	6,960	64½	Engine had made 281 million revs. altogether, but load during first 216½ millions is unknown. Inertia of piston and piston-rod is taken into account in calculating load.
79	12,500 16,750	76½	Increase of stress due to gradual increase of load; capital example of fatigue.
80	14,300 19,100	96 70	Engine had made altogether 166 million revs., but during first 96 millions the stresses were less.
81	5,400	193½	
82	17,160	49	Mean piston-speed was 730 feet per minute. Stress unmodified by inertia would have been 31,100 lbs. per square inch.
83	7,960	24	Mean piston-speed 803 feet per minute. Stress unmodified by inertia would have been 12,300 lbs. per square inch.
84	4,700		
85	5,000 10,000	155	Breakage of arm which drove air-pump. Lower stress corresponds to pressure of 10 lbs. per square inch upon air-pump bucket; higher to pressure of 20 lbs.
86	5,100 6,200		Gradually increasing stress. Engine made in 1835, but load in early life unknown.
87	10,400		

occur occasionally. The only other precaution the author can suggest is to cover the bolt heads by a thin flat ring fastened to the junk-ring by set-screws, but it is questionable whether the remedy is not as bad as the disease; on this point he would be glad to hear other suggestions.

McNaught and Main Links.—Of these twenty-one were McNaught links, and the remaining one was a main link. Most of them gave way at the bottom bend, most likely at the weld; for formerly links were generally welded, instead of being cut out of a solid slab, as is now the usual practice. Another fruitful cause of breakage was the twisting of round-backed brasses. The pillars in links should always be made with flat ends, and the brasses which they support with flat backs. Also many McNaught links, like McNaught cross-heads and beam centres, used to be made far too weak, probably in accordance with a rule of the same kind as the following, which when the writer first went to Manchester was communicated to him as representing the best engineering practice: namely that the piston-rod should be one-tenth the diameter of the cylinder, and the cross-head arms the same diameter as the piston-rod. This rule may have given sufficient strength with low pressures; but it was altogether inapplicable to McNaught cylinders and high boiler-pressures.

Fly-wheels.—Of the nineteen breakages of fly-wheels, ten were breakages of arms from internal stress, bad fitting, or causes not ascertained; one was the fracture of a wrought-iron hoop shrunk upon a boss, which arose either from an imperfect weld or from excessive shrinkage; and eight were cracks in fly-wheel bosses. Three of these cracks occurred in old single-faced bosses, to which the arms were secured by bolts; the cracks extended circumferentially from bolt-hole to bolt-hole, and were due to fatigue of the metal. The remaining five cracks were caused by driving the keys by which the wheels were held; in four of these cases the fractures started from the corners of rectangular key-ways, and in the fifth between the key-ways. In this last instance the wheel was 14 ft. 9 ins. diameter, with a bored boss secured to the shaft by two sunk keys; the wheel got loose, as large wheels held in this way generally do; and in trying to fasten it again the boss was split. The writer's experience is that large wheels cannot be held in this way, but should be hung on four or more broad keys with plenty of substance in them, bedded upon flats on the shaft, and if possible driven two and two from opposite sides of the wheel. The corners of the key beds in the boss should be rounded. If, in spite of large bearing surfaces and careful fitting, wheels persist in getting loose—as sometimes happens when they carry a spur rim with double helical teeth, or when the load is liable to sudden changes as in rolling mills—the best plan is to fill the places between the keys with hard wood and steel wedges. A wheel so secured will not be got off without "winged words."

Air-Pumps and Condensers.—Of these there are thirteen instances of breakdowns, divisible as under :—

TABLE 17.—*Air-Pumps and Condensers.*

Cause or nature of Breakage, and Number of cases.

A	Fractures of flat surfaces of horizontal air-pumps	4
B	Fracture of water head of surface condenser	1
C	Fracture of flat-sided valve-chest of circulating pump from shock . .	1
D	Corrosion	3
E	Failures of holding-down bolts	2
F	Nozzle torn off condenser by exhaust pipe, owing to cylinder being lifted by water on top of piston	1
G	Air-pump barrel fractured without apparent cause	1
	Total breakdowns of Air-Pumps and Condensers . .	13

The large flat surfaces which so often disfigure horizontal air-pumps should be abolished, specially when the speed of the plunger is high, or when the overflow pipe from the hot-well is long and discharges above the level of the pump. Often the plungers of horizontal air-pumps, and sometimes those of circulating pumps, move faster than the water can follow them; and then there is shock, which tells upon the weak flat surfaces. Sometimes overflow pipes get filled up, and the pressure required to force the water through them becomes excessive. To prevent this the hot-well should be provided with a safety-valve in the shape of a vertical pipe having an open top. With regard to ordinary vertical single-acting air-pumps and condensers, all that can be suggested is to set them in dry, accessible, and well lighted places.

Cranks.—Of the twelve cranks which broke, eleven were of cast-iron and one of wrought-iron. This last broke across the arm, just below the eye for the crank-pin; it had evidently been cracked for some time. The stress due to the pressure on the piston, without correction for inertia, was 6,130 lbs. per square inch, and the number of revolutions made was 66½ millions. Of the cast-iron cranks, one was certainly broken by water in the cylinder. The others when broken proved to have been partly cracked for some time; four of them failed by fractures starting from sharp corners of key-ways or cotter holes; and six without any apparent cause, four in the boss and two in the arm. Doubtless these and other like breakages were due in part to stresses set up in cooling, and to shrinkage; but whether they were so or not, it is quite clear that the substitution of wrought-iron for cast-iron cranks would practically prevent one class of breakdowns. If cast-iron cranks be used, square-cornered key-ways should not be allowed.

Gudgeons in Beams.—Of the twelve broken gudgeons, five of wrought-iron or steel were McNaught gudgeons; three of wrought-iron and one of cast-iron were main gudgeons; one of wrought-iron was a gudgeon at the piston-rod end of a beam; and one also of wrought-iron was an air-pump gudgeon. The twelfth was not really a gudgeon, but was one of a pair of cast-iron saddles, with bearings for McNaught links, bolted upon the beams in place of McNaught gudgeons, for which latter the beams were not prepared. All the five McNaught gudgeons broke inside the beams at the end of the bearing surface, as shown in Fig. 101, Plate 134, which represents one of them. They were moreover weak, or held in weak bosses on the beams. In the instance illustrated in Fig. 101 the boss was weak, and it was with a view to strengthen it that the wrought-iron hoops *hh* shown in the sketch had been shrunk on. The boss or gudgeon however sprung under the load, and the gudgeon could not be held tight. Assuming the load to have been equally distributed upon the two bearings, the strain at the inner end of each would have been 7,900 lbs. per square inch; while, if the leverage be measured from the middle of the bearing to the fracture, the strain would be 16,000 lbs. per square inch. The life of the gudgeon corresponded with 136 million revolutions of the engine. It is not clear why McNaught gudgeons should generally break in this particular place. Reverting to the suggestion previously made (page 549), that consideration should be given to what might be expected to happen if the parts were made of some very extensible material like india-rubber, it will be seen from Fig. 102 that under stress the gudgeon if loose would bend, and would bear alternately at *a* and *c* and at *a′* and *c′*. The sharp edge of the bearing surface in the beam at *c* might then act as a file, and start a skin crack in the gudgeon, which would gradually eat its way through the latter. If so, the remedy is to make those parts of the gudgeon which are gripped by the beam about ¼ inch larger in diameter than the rest.

Of the other six gudgeons, four of wrought-iron broke at abrupt changes of section, and two without any apparent cause. The cast-iron saddle broke from weakness, the stress upon it having gradually risen to 11,000 lbs. per square inch; the number of revolutions made by the engine is believed to have been 29½ millions.

Crank-Pins.—Of the eleven crank-pins which broke, two were of Whitworth fluid-compressed steel, one of Siemens steel, one of Bessemer steel, and seven of wrought-iron. The resulting damage was considerable. The life of both the Whitworth pins was short. One of them broke at the junction of the neck or journal with the shank, as shown in Fig. 89, Plate 133, after having made 13½ million revolutions. The shank upon which the crank was shrunk was slightly tapered, the smaller end being next the journal. At the junction there was a small fillet of ¼ inch radius. The maximum stress at the fracture was about 12,000 lbs. per square inch. The surface of the fracture was as usual convex on the journal, and concave in the crank. The cause of the breakage was not ascertained. The second Whitworth pin, shown in Fig. 90, is more instructive. The journal or neck was 7 inches, and the shank $7\frac{5}{16}$ inches diameter. The latter was $\frac{5}{8}$ inch longer than the hole in the crank, and projected $\frac{5}{8}$ inch from the face of the crank. Upon the projecting part was shrunk a ring *r*, $\frac{5}{8}$ inch thick and 1 inch wide, to fill up the space between the face of the crank and the connecting-rod brasses. The pin broke between the ring and the face of the crank. The stress due to the steam pressure, reduced by the inertia of the moving parts, was about 8,600 lbs. per square inch; yet the life of the pin was only 6 million revolutions. In the writer's opinion the fracture was caused by the skin of the shank having been sheared by the grip of the crank contracting upon it; the skin being once damaged, the extension of the crack would be only a matter of time. The same action is seen in gudgeons or centres shrunk into cross-heads. Wherever a pin or centre is secured by shrinkage, it is advisable that the part within the contracting metal should be of larger diameter than the part outside, as shown in Fig. 100, Plate 133. This is particularly important when the material is steel.

The remaining instances represented in Figs. 91 to 99, Plate 133, also teach a lesson. In each the pin was formed with a collar between the shank and the journal; with the two exceptions shown in Figs. 95 and 96, the shank was of the same or less diameter than the journal; and the pin was put in from the face of the crank, and secured either by a nut, Fig. 91, or by a cotter, Fig. 95, or by riveting at the back, Fig. 92. All these either broke inside the crank or got loose, breaking the screw thread or the riveting. The pins represented in Figs. 91 and 92 did not themselves actually break; but their fastenings—the screw and nut in Fig. 91, and the riveting at the back of the crank in Fig. 92—gave way, and allowed the pins to get loose, thus necessitating their replacement. In both instances the engines were stopped before the pins had come quite out of the cranks. In the remaining seven instances, Figs. 93 to 99, the pins broke in two, and serious damage resulted. The stresses under which the failures occurred, and the numbers of revolutions made by the engines previous to the breakdowns, are given in Table 18; the stresses are corrected approximately for inertia, but do not include the shearing stresses, which however are small.

TABLE 18.

Seven Crank-Pins broken inside eye of crank.

See Plate 133.	Stress per square inch. At inner end of journal.	At section of fracture.	Millions of Revolutions.	Material of Crank-Pin.
Fig.	Lbs.	Lbs.	Millions.	
93	6,330	14,600	164	Bessemer steel.
94	6,370	11,200	200 ?	Wrought-iron.
95	5,500	8,800	88	Wrought-iron.
96	8,190	16,400		Wrought-iron.
97	8,580	10,470	22½	Siemens steel.
98	9,650	17,300	87	Wrought-iron.
99	10,200	16,600	8	Wrought-iron.

Pins held in this way—with a collar between the shank and the journal—are not secure; they get slack, and wear away the bearing surface next the face of the crank. Thus the point of support is thrown back, and the leverage at which the pressure acts is increased, till the strain becomes too great for the strength of the material. That no less than nine out of eleven broken crank-pins should have been so held is strong evidence against the method: especially when it is added that the number of crank-pins so held is insignificant, at least among the classes of engines the writer has to deal with. Crank-pins should be made as shown in Fig. 100, Plate 133, and should be forced into the cranks by hydraulic pressure, or the cranks should be shrunk upon them.

Beams.—There were only six instances of broken beams, all of cast-iron. In four of them the beam broke in two between the piston-rod end and the main centre, owing in one case certainly, and in the others probably, to water in the cylinder. In the fifth case one of the bosses for the McNaught gudgeons was broken off through weakness. The loads on McNaught gudgeons are usually heavy in proportion to the general dimensions of beam engines, owing to the short strokes of McNaught pistons and the consequent large diameters of McNaught cylinders; and the bosses on the beams are frequently far too weak, as in Fig. 103, Plate 134. In such cases it is better to cut them off entirely, and to fix the gudgeons as shown in Fig. 104.

The sixth breakage is interesting because it seems to have resulted simply from fatigue or gradual deterioration of the beam, which like the five preceding was of cast-iron. The engine was made in 1847 as one of a pair of condensing engines; and as far as could be ascertained it worked in this way till 1872, when the cylinder was replaced by a smaller one with Corliss valves; and with an increased boiler-pressure this single engine was set to drive the whole of the load previously driven by the pair. It worked in this way till 1880, when the other engine was again coupled up, and the pair worked compound. In 1892 some slight fine cracks were noticed near the middle of the beam, in the flange and also in the web. About three months later the cracks in the web had become well developed, the top flange was found to be cracked entirely across and the bottom flange about half way through; in fact the beam was on the point of giving way. So far as is known there had been no abnormal stress or shock to cause the cracks. The strain previous to 1872 is not known; probably it was between 1¾ and 2 tons per square inch; up to this date the engine made about 130 million revolutions. From 1872 to 1880 the strain was increased to about 2½ tons per square inch; during this period the engine ran 41 million revolutions. Since 1880 the strain has been about 2 tons per square inch, and the engine has made 62½ million revolutions. In calculating the strains the inertia of the parts has been neglected, and the beam treated as a girder of I section, neglecting the boss for the main centre and the rib and mouldings which run along the web. On the other hand the weights of the piston and the connecting-rod hanging on the ends have not been considered. It is therefore probable that the foregoing figures are not materially different from the facts. If so, the strains were not excessive as compared with general practice. According to calculation cast-iron beams are generally strained to between 4,000 and 5,000 lbs. per square inch, and many are strained to about

7,000 lbs.; but the latter the writer considers is too much. This instance then seems to be purely one of fatigue of material.

Slide-bars.—Of the five breakages it is only necessary to say that four were top slide-bars and one a bottom bar; and that, except in one case where the cause was not ascertained, the breakage was the result of heating, or at all events occurred simultaneously with heating.

Ropes.—Only three cases of damage from belts or ropes are recorded. The breakage of a rope sometimes causes considerable damage by pulling down shafting and fixings; and it is highly desirable that precautions should be taken to prevent such accidents. The simplest apparatus is a lathe wire or shield, stretched across the breast of the rope drum just clear of the ropes: so that any broken strand unwrapping may catch it, and by a suitable arrangement, such as liberating a trigger and freeing a weight, may close the runaway valve and stop the engine. It is well also to have a bell hung upon the apparatus, to warn the engineman of approaching danger.

Discussion.

Mr. Longridge exhibited in illustration of the paper a collection of specimens of the smaller parts which had failed and caused breakdowns of stationary engines, including bolts, nuts, cotters, and other fastenings, rods, gearing, crank-pins, &c.

Capt. H. Riall Sankey congratulated the author on his paper, and considered he had the advantage of occupying a unique position, in that a great number of breakdowns came under his notice, and unlike an engine builder he could not feel any reluctance in making them known publicly. The paper, upon which great labour must have been bestowed, bristled with points for discussion. The first

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he should like to refer to was one which recurred many times in the paper, namely the fatigue of metals and the effects of varying stresses. In the early days of the Willans engine certain crank-shaft fractures had occurred without apparent reason, inasmuch as these shafts had been proportioned according to the best practice, and even an ample margin of extra strength had been allowed; moreover there was no visible initial flaw in the metal. Evidently there had been some unknown or unexpected action at work. It had devolved upon himself to investigate the matter; and his investigations had been based upon Wöhler's experiments, or rather upon the deductions which had been drawn from those experiments by Professor Unwin in his "Elements of Machine Design." These investigations showed that there were two points at which such a crank-shaft was more severely stressed than at any others; and at those two points not only was the range of stress greater than at any other point in the crank-shaft, but it exceeded what would be supposed to be safe, or at any rate it left too small a margin of safety, according to the experiments of Wöhler. The obvious remedy was to strengthen the shaft sufficiently at those two points. The experience that had now been gained for a number of years had borne out the theory completely; for whereas the earlier shafts, with only two exceptions, had all broken at either one or other of the two weak points indicated by theory, only three of the strengthened shafts had broken up to the present time, and not one of these breaks had occurred at either of the two weak points, but they had all been due undoubtedly to flaws in the steel, which had not been detected during manufacture or examination. In Fig. 105, Plate 135, was shown a curve of coefficients for safe stress, plotted from Wöhler's experiments, which had been in use in Messrs. Willans and Robinson's drawing office for some time; it had been found useful there, and he hoped it would be found useful in the same way to others. The vertical ordinates gave the ratio of the minimum stress to the maximum stress. If the two stresses were of the same sign, that is, either both tension or both compression, the ratio was positive, and was found above the horizontal datum or zero line: if one of the extreme stresses was compression and the other tension, then the ratio was negative, and was found below the zero line. The corresponding horizontal abscissa of the curve was the coefficient wherewith to multiply whatever was considered to be the safe amount for a continuous steady stress on the metal. Suppose, for instance, it was found that the minimum stress at any particular point in a piece of mechanism was 1,200 lbs. per square inch, and that the maximum stress was 6,000 lbs., both being tension or both compression: then their ratio was $1,200 \div 6,000 = 0 \cdot 2$, and from the curve it would be seen that the ratio $+ 0 \cdot 2$ corresponded with the coefficient $0 \cdot 7$. If then the material used was considered to be able to bear safely a steady load of 10,000 lbs. per square inch, this safe limit multiplied by $0 \cdot 7$ gave 7,000 lbs. per square inch as the safe limit at the point under consideration in the mechanism. It might therefore be said that at this point the piece of mechanism was unnecessarily strong. If however the maximum stress was of a different sign from the minimum stress, one being tension and the other compression, then their ratio was, for instance, $- 1,200 \div 6,000 = - 0 \cdot 2$, and from the curve it would be seen that the corresponding coefficient was $0 \cdot 53$: so that the safe stress would now be $10,000 \times 0 \cdot 53 = 5,300$ lbs. only. As the maximum stress was 6,000 lbs., the curve in this instance would give warning to make that part of the mechanism stronger, until the safe stress allowed by Wöhler's experiments was equal to the maximum anticipated, or greater. In page 559 of the paper was given an example in which the stresses varied from $\pm 2,500$ to $\mp 8,200$ lbs. per square inch; and as the signs were reversed, the ratio became $- 2,500 \div 8,200 = - 0 \cdot 3$, for which from the curve the corresponding coefficient was seen to be $0 \cdot 5$. If here again 10,000 lbs. were assumed to be the safe stress for a steady load, the safe limit for the varying stress would be only 5,000 lbs. as against the actual 8,200 lbs. This calculation therefore gave some clue as to why that particular piece of mechanism had broken.

The instance given in pages 551–2 of a complete breakdown, which had started from a small cause, might be capped by one which had occurred to a Willans engine at Bradford, where a relief valve of a vertical triple engine, in which the three cylinders were arranged

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tandem fashion, broke in the high-pressure cylinder, and getting into the cylinder gradually broke parts of the trunk valve-motion into pieces; these in turn came down into the intermediate cylinder, breaking the piston, and the next trunk; and the fragmentary contents of the two cylinders went down into the low-pressure receiver. The operation took about a month, the engine making a great noise all the time; and he was told that it was "heaving" at its foundation. At last a piece of metal got inside the low-pressure cylinder, and instead of this piston being broken the cylinders were wrenched off.

The suggestion in page 549 he thought was excellent, to consider the materials as though they were india-rubber. He had himself sometimes considered his finger, as though it formed the piece of mechanism in question: which had the advantage that, if the finger were worked vigorously enough, its owner could almost enter into the feelings of the piece of mechanism.

Mr. Alfred Saxon, having been brought up in a shop mainly occupied with the repair of breakdowns, had been largely concerned with that class of work, and could confirm from his own experience of similar instances many of those furnished in the paper. It was due to engineers like the author that today, when a breakdown occurred, proper calculations were made for determining whether the part which failed had broken through faulty construction, or defective material, or whether it had really been strong enough to resist the stresses to which it had been subjected in work. Previously the ordinary method had been a sort of rule of thumb only. Now that so many engines were insured, few breakdowns occurred in which the insurance societies had not some advice to give to their insurers. Consequently the makers of engines had rather less scope than formerly in the execution of breakdown work. The effect however had been that breakdowns were now more scientifically and more thoroughly investigated than had formerly been the case; and also that the parts which had been found to give way most frequently had been strengthened, and were still being further strengthened, in Lancashire mill engines.

In connection with the breakdown of valves and valve-gear, a highly important point was lubrication, which in his opinion had had more influence on such breakdowns than anything else; it had sometimes been stopped altogether, or the engine had perhaps not been fitted with proper lubricating appliances. In most Lancashire mill engines there was now continuous lubrication of all valve-chests, crank-shaft necks, and other working parts: in fact wherever automatic and constant lubrication could be applied it was provided, at any rate in the best engines.

When rope driving had to be placed in sequence to spur gearing (page 542), he thought that as an alternative, instead of diminishing the size of the rope pulleys, and consequently reducing the speed of the ropes and increasing their number, the best plan was to use steel gearing, as recommended in page 544, and to keep up the rope speed as nearly as possible to 4,750 feet per minute, which seemed to be the speed generally agreed upon as the best for working the ropes up to their highest efficiency.

In Fig. 2, Plate 122, was shown a design of a fly-wheel, which, along with the author (page 544), he could certainly recommend. It had several advantages, one of which was that it enabled engines to be used of a less bulky character and to be run at a greater number of revolutions per minute without exceeding a safe speed for the toothed rim. Consequently with fly-wheels of that design less costly engines could be put in, but as powerful as the engines that were put in with fly-wheels constructed as shown in Fig. 1; his own firm had for many years been making fly-wheels somewhat similar to the design shown in Fig. 2, which had given great satisfaction.

As to the number of teeth in the pinion, it might be remarked that the expression "fine pitch" in page 544 could have after all only a relative significance, as would readily be gathered from the examples of spur gearing in Table 4. Here the first example had 4½ inches pitch and was transmitting 700 horse-power, while the last example was a pinion with the same pitch transmitting 1,360, or almost twice the horse-power of the first. The same pitch of 4½ inches he thought would be called coarse for the 700 horse-power, and fine for the 1,360. Other examples given in the table

(Mr. Alfred Saxon.)

went as high as $5\frac{3}{4}$ inches pitch for transmitting only 1,150 horse-power.

The President gathered from the author's remark about fine pitch that it was better to have a large pinion than a small one, wherever practicable.

Mr. Saxon agreed that the question of pitch and number of cogs could hardly be dealt with in detail without going into it at too great length; it was impossible to lay down any hard and fast rules. As to the best rim speed he should much like to have the benefit of the author's opinion.

The use of trunk motions for driving air-pump buckets (page 549) he quite agreed ought to be discarded. If the lift of the air-pump was not great, there would be practically no difference in the vacuum between a solid bucket and a bucket with rings (page 551); but if the lift of the pump was increased to a considerable height, as frequently occurred, then a bucket with rings undoubtedly produced a better vacuum than a plain bucket without packing.

All Lancashire engineers he was sure would feel indebted to the author for the trouble he had taken for many years in pointing out the necessity of attending to the minuter details of stationary engines, and of increasing the strength of what had proved to be the weak parts, as shown by the statistical record compiled in the present paper.

Mr. M. Holroyd Smith noticed that in pages 568–9 the subject of keys and key-ways had been enlarged upon. There were two ways in which profit could be derived from a paper of this kind: by realizing the causes of breakdowns, and by trying to suggest some method of preventing their future recurrence. Like all other engineers, he had experienced great difficulty and trouble with wheels bursting and with key-ways failing; and he had been led to devise the method of keying shown in Fig. 107, Plate 135, which he had found very useful. The usual method of keying might be illustrated by Fig. 106, where a rectangular key was let equally into the shaft S and into the hub H of the wheel. Supposing the wheel was driving the shaft in the direction of the arrow, the only useful part of the key was the oblique shaded portion, and the two unshaded corner portions were absolutely useless. All knew to their cost how frequently it occurred that keys were too hardly driven in, as noticed in page 569; if the key was driven in too tight, there was a tendency to burst the boss by too much sledge-hammer work on the key. Unless in the working of the wheel and shaft so keyed the reaction between them produced both an outward radial pressure to hold the key in the wheel key-way, and also an inward radial pressure to hold it in the shaft key-way, the key would soon begin to rock; and then the consequence was that, towards whichever side it rocked itself tight, it thereby tended to burst the key-ways, or rather the key-way in the boss, which was the only one that could be burst of the two. As a rule it would be found that the bosses so keyed, if not burst by driving the key in, were burst afterwards by the key getting slack and rocking over. The method of keying shown in Fig. 107, it would be observed, was arrived at by simply utilizing the useful shaded portion of the key in Fig. 106, and rejecting the useless unshaded corners, so that the whole of the key-way and key at K was now doing useful work in Fig. 107. With a wheel running in the direction shown at K, it was not necessary with this key that there should be any amount of radial pressure either outwards or inwards; the whole of the reaction in working was holding the key tight both in the wheel and in the shaft. In fact if the key was originally fitted steady and secure, it would be found just as efficient for running in the contrary direction as an ordinary key was. But when the wheel had to run first one way and then the other, his practice was to repeat the key reversed on the opposite side of the shaft at L for running in the reverse direction. By the same method of keying he had also found that the wheel was enabled to slide laterally along the shaft: the key acted admirably as a loose feather. In page 545 attention had been drawn to the necessity of having helical wheels so adjusted that they could move from side to side, so as to keep the pressure equal upon each half of the double teeth. A helical pinion fixed on a key such as

(Mr. M. Holroyd Smith.)

now described would be able to work laterally in the manner desired.

Mr. **William Schönheyder** thought the illustrations furnished in the diagrams were many of them a pitiful exhibition of want of knowledge in designing the work. For holding large wheels on their shafts the author had recommended broad keys bedded upon flats on the shaft (page 569); but with such an arrangement the radial distance from the centre of the shaft to the middle of the flat was only a little less than the radial distance to the corners of the flat; whence it followed that the whole driving power of the wheel depended largely upon the friction between the key and the shaft, and therefore the keys had to be driven in with great force, and a number of them had to be employed, while the boss of the wheel had to be made of excessive strength to resist being burst off in driving them. The proper way of constructing a key he thought was as shown in Fig. 108, Plate 135, especially where the stress was in both directions, first one way and then the other. Here it would be seen that the key was left slack at top and bottom, and was made with sloping sides where it fitted into the key-way in the shaft; it was possible then to fit it perfectly tight in the shaft. With a rectangular key sunk in a rectangular groove, it was impossible to make it fit sideways as tight as it should do in order to take up the stress; and therefore the effect of the ordinary key sunk in a shaft was really to produce friction at the top and bottom of the key and not to fit sideways. The sides of the key were then practically useless. Instead of the form shown in Fig. 108, it was possible that a still simpler form would do nearly as well, namely a key of slightly rhomboidal section, nearly but not quite rectangular; imagining it divided across by its shortest diagonal line, one half should be sunk in the shaft and the other in the wheel. It would then take the stress in either direction of running, but would not be quite so good as the plan shown in Fig. 108.

Professor **T. Hudson Beare** was particularly grateful for the information given in the paper with regard to the effect of repeated stresses on the life of different parts of engines. Recently he happened to have been lecturing upon this very subject to his students; and the extensive series of examples given by the author, of the effect of stresses repeated for rather a high number of times, would be most valuable to him, as they would be also, he should imagine, to every engineer engaged in designing work. A simple rule to remember, which he thought would have prevented some of the errors made in the design of the particular engines whose breakdowns were here illustrated, was that the effect of a stress was not to be measured by the mere magnitude of the tension or compression, but by the range of the stress, that is, by the difference between its maximum and minimum values. Naturally when dealing with stresses which were at one time compressive and at another tensile, the two amounts should be added together: for instance, in one of the examples given in page 559, where the calculated stress was 10,180 lbs. per square inch, in tension and in compression alternately, he thought that if these two amounts had been added together, and it had been realized that the shaft in question would be working at an equivalent of 20,360 lbs. per square inch, some hesitation would have been felt before putting in so light a shaft as that actually employed. It was easy to arrange a convenient rule, taking account of the range of stress as well as of the maximum stress, somewhat on the same plan as that described by Capt. Sankey (page 576) for determining the safe working stress. His own plan was to adopt a uniform safe working stress, and to take as the load the maximum load plus the product of the range of stress multiplied by a constant coefficient. The result came to much the same as Capt. Sankey's plan of finding a variable safe working stress by the use of a variable coefficient. If it had been remembered that the range of stress was one of the vital points, he thought so many errors would not have been made as were at present met with.

The example cited in page 574 of the fracture of a cast-iron beam seemed to him hardly to prove that fatigue had caused it. The beam he understood had shown first a tiny crack, and then that crack had gradually developed.

Mr. **Longridge** pointed out that it was not a single crack only, which had first attracted notice; there were a number of slight fine cracks all about the face of the beam, radiating out from the centre.

Professor **Beare** added that, after those cracks had once been started, there would be a gradually increasing stress upon the diminishing section of the beam. As to what might have caused the first cracks, he could not venture to offer any explanation; but where a crack had started he thought it was rather frequently attributed in error to fatigue. The original cause of a crack he believed was generally obscure, and to ascribe it to fatigue seemed to him to be only evading the difficulty; after the crack had once started, the stresses increased gradually in the material, and naturally the crack would go on spreading itself more and more rapidly under stresses repeated so many million times. The experiments carried out by Wöhler and afterwards continued by Bauschinger showed conclusively that the main danger of repeated stresses was when the range of stress was considerable, and particularly when stresses of tension and compression alternated with great rapidity. As to ensuring safety by keeping stresses well within the limit of elasticity, this depended altogether upon what was the limit of elasticity of the material. A piece of steel might appear to have a limit of elasticity of perhaps 30,000 lbs. per square inch when tested in tension only; but if then it was tested at once in compression, it would no longer have so high a limit of elasticity when again subjected to tension. There was need therefore to recognise that the limit of elasticity as at present understood was a variable quantity. There might indeed be some natural limit of elasticity, about which not much was yet known; and if the load could be kept below that natural limit of elasticity, its repetition for an unlimited number of times he thought would not have the slightest effect on the material. The rule which the author had found in Manchester when he went there (page 568) was only another brilliant example of those so-called engineers' rules, which when they were first used by engineers thirty or forty years ago had perhaps been good rules of practice for the pressures then dealt with; they had however been perpetuated, often unfortunately without the necessary explanation of how they had been arrived at, until, under the conditions which should now regulate engine building, they had entirely ceased to be of the slightest value. Such rules he thought should be carefully avoided.

Mr. Henry M. Rounthwaite said the exceedingly interesting examples given in the paper of the failures of details, and the highly valuable hints offered as to how to avoid accidents of the kind, led him to wish greatly that the author had dealt with the wider question of the general design of the engines used. It had only occasionally been his own good fortune, as a marine engineer, to have opportunities of seeing beam engines or horizontal engines at work; and he thought it would be of great interest to marine engineers if the author would give them the benefit of his opinion on the general design of these engines. Why for instance did mill engineers, if they had discarded beam engines, still adhere to horizontal engines often 30 or 40 feet long, bedded upon brickwork, which was always liable to settle and so give rise to fractured bedplates, cylinders that were out of line, shafts that did not run true, and other troubles? Whereas, by adopting the inverted marine type of engine, with a bedplate of small area and three or four feet deep if necessary, they would get rid of all these evils, besides being able to run at a much greater number of revolutions per minute, and thereby, in some cases at least, avoid the use of gearing altogether. The engines would then be both smaller and cheaper, and also, he felt certain, less costly to maintain than the present horizontal ones.

Mr. Basil H. Joy thought marine engineers would hardly be surprised to find in Table 1 that valves and valve-gears headed the list of breakdowns by about 72 per cent. above the next highest item. In marine engines these parts had indeed been the subject of much difficulty in late years. The only remarkable point about them seemed to him to be that with the Corliss valve-gear the number of

(Mr. Basil H. Joy.)

breakdowns in Table 2 was only seven out of the large total of 213, probably owing to the slow speed at which such engines were run. Presumably most of the engines dealt with in the paper were of an early make, and perhaps the examples if given in full might not have proved so valuable as they might appear to a superficial survey, because the engines had been designed some time ago, and probably the designs were not such as would be repeated nowadays. The way in which valve-gears were now designed he thought was pretty much by the simple rule of merely repeating what had been done before: there was a certain amount of calculation, but there was a great want of knowledge as to the actual amount of power required for driving valves.

In connection with the numerous breakdowns of air-pump buckets and foot-valves in Table 6, it might be interesting to call attention to the device of Mr. Frederick Edwards,* which did away entirely both with foot-valves and with bucket-valves. By this plan he had been informed that, while the air-pump and engine continued running at full speed, the air-pump valves had been entirely renewed without any perceptible difference being produced in the vacuum shown. That might be a way of avoiding air-pump difficulties in future, so that, although there might be a breakdown of air-pump valves, it would not stop the engine. The suggestion in page 551 that small brass valves in the bottom of the air-pump barrel, if they got loose, were too small to do damage, seemed hardly to agree with the account given in the same page of the great extent of damage which had followed a small breakage of a bolt.

With regard to the remark about slide-bars (page 575), that out of five breakages four were top slide-bars and one a bottom bar, it would be interesting to know whether all the five engines were running the same way round: that is, whether it was always the ahead bar that gave way.

Mr. A. H. Barker was tempted, by the great interest attaching to the valuable records now presented of breakdowns of stationary engines, to offer the suggestion that similar statistics might with advantage be collected of all breakdowns in trial trips of marine engines and machinery. Most of the breakdowns seemed there to occur in the auxiliary machinery; which he was inclined to attribute to the weight and strength of the parts being kept down too low. If such failures were recorded and criticised in a manner similar to those dealt with in the present paper, their recurrence might be guarded against, and improvement might be made where he thought it was much needed.

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* "Engineering," 14 August 1896, page 221.

Mr. Charles Day noticed in Table 2 that the Corliss valve-gears represented but a small proportion of the valve-gears which had broken down. The number of instances had been quoted (page 586) as only seven out of the total of 213; it would be more correctly stated, he considered, as thirteen: namely four for dashpot rods, six for brackets, and three for other parts. Seeing that probably a large number of the engines dealt with in the paper were Corliss engines, he thought so low a proportion of breakdowns spoke most favourably for the Corliss valve-gear, especially as the makers of Corliss engines were so frequently told by probable purchasers of engines that they did not want to get an engine which was fitted with such an elaborate contrivance.

With reference to spur gearing, his own experience, though small compared with the author's, had also been that it was too liable to produce breakdown from backlash. In some instances he had known repeated breakdowns to occur in the same mill from this cause. The suggested use of steel wheels (page 579) he rather thought would be a sort of brutal remedy, simply putting in wheels which could not well break, instead of removing the real cause of breakage. In several mills he knew it had been done, with the result that the people in the neighbourhood had had to remove in consequence of the noise; the improper stresses had not been remedied at all; they had simply been met by making a wheel which they could not break easily. In some instances in which he had had to devise alterations, he had tried to see how a plan of rope-driving could be substituted for gearing. Generally speaking the difficulty he had met with had

(Mr. Charles Day.)

been that the speed of the wheels was too slow for rope-driving to be substituted efficiently. In such cases he thought the true remedy was that which had been suggested in the paper, namely careful consideration and accurate construction of the teeth. If combined with the use of cast steel, all the better.

For air-pumps the author had suggested plain buckets without any packing whatever (page 551). The firm with which he was connected—Messrs. Cole, Marchent, and Morley, of Bradford—had repaired several breakdowns due to metallic packing rings wearing thin and then overlapping; and they preferred buckets with simple water grooves. When water grooves were used he had found that, where the water was slightly corrosive, the buckets had corroded sometimes rather rapidly all round along the edges of the grooves. Some of the buckets so corroded had been replaced by buckets with no grooves, that is, absolutely plain; and these had worked with equal efficiency.

The deep circumferential groove in the main shaft illustrated in Figs. 55*a* and 55*b*, Plate 126, and described in page 559, was indeed remarkably peculiar; he could only imagine that it was due to the use of bad oil. Probably at some time when the eccentrics had been lubricated with bad oil, the small quantity that overflowed had caused the corrosion round the shaft.

In connection with governors (page 563) the author had advised some sort of efficient runaway-motion. Most makers of mill engines he thought did put a runaway motion connected with the governor; but unfortunately it was so frequently found to be intentionally thrown out of gear. In nearly all the engines he had been called to examine he had found the runaway motion purposely blocked out of gear, for the reason that, if it acted properly in shutting off steam when the governor ceased to revolve through failure of the driving gear, that is, when the governor balls fell to their lowest position, it must come into action every time the engine stopped: therefore while the governor was in its lowest position, the engine could not take steam. The result had been that the engine could not be started without lifting the governor up and propping it up; and consequently it was not uncommon to find underneath the bottom collar of the governor a piece of wood or a ferrule, preventing it from falling to its lowest position, even if the driving gear itself should fail. The remedy obviously was that the knock-off or runaway gear should be actuated by an independent governor, or should otherwise be specially designed to overcome this difficulty.

With regard to the pistons, he should like to ask whether the author had met with any instances in which the pistons had broken through weakness. It had often seemed to himself that the usual mode of cottering a piston upon its rod almost cut the piston in two, and left it with so deep a groove, frequently right across, that the steam pressure might break it across. Whether any such breakages had ever occurred, he did not know; but in making designs he had always felt some reluctance to have recourse to cottering pistons. A recent practice of his firm was to make a deep piston, secured upon its rod by a nut, and to add an external junk-ring all over the back of the piston so as to cover the nut absolutely. A nut gave much better support to the piston than a cotter did. The objection to an external nut was the great clearance surface, and also the fact that it was so liable to corrosion; but this method of arranging the nut seemed to have the advantage of the better support afforded by a nut, without the usual disadvantages.

In using mild steel for cranks, he had sometimes noticed that on putting it into a lathe it appeared too hard; and in such cases he had invariably rejected those cranks. He should like to ask whether there was any reason to fear lest mild Siemens-Martin steel, which in its ordinary state would seem to be highly suitable for cranks, might take a temper when heated and shrunk on the shaft, and might thereby be rendered unsuitable. In view of this possibility his firm had felt some fear in using it, and had taken special pains to ensure the material being of a soft quality and unlikely to take the slightest temper.

Mr. Longridge had for many years held that the fatigue of material under repeated stresses alternately tensile and compressive was a highly important point; but he had found it was one of the most difficult to enforce upon mill-owners and manufacturing

(Mr. Longridge.)

engineers. There seemed to be an impression among mill-owners that, if a piece of steel would stand 20 tons per square inch in a testing machine, it must be impossible to break it in an engine with any less load. The more this subject was ventilated, the better would it certainly be for engine-builders and mill-owners; and he was glad that so much stress had been now laid upon it by the remarks of Capt. Sankey (page 576) and of Professor Beare (page 583).

About the beam mentioned in page 574, his view was, not that the extension of the small cracks into the larger had been the result of fatigue, but that the initial appearance of the small cracks themselves was what had been caused by fatigue. There seemed to be absolutely no other reason why they should have been started at all; and he therefore considered them to be due to fatigue. If the stress was only small enough, he understood Professor Beare (page 584) to be of opinion that it might be continued any number of times, and produce no effect. The impression left upon his own mind from what he had seen of breakdowns was that a stress of any intensity whatever, however small, if repeated often enough would ultimately produce fracture.

For Mr. Holroyd Smith's and Mr. Schönheyder's illustrations of keying (pages 580–2) he was much obliged. The object of the paper was to elicit information of this kind; and he certainly thought these plans had a good deal to recommend them, especially Mr. Holroyd Smith's.

He could not agree with Mr. Saxon's opinion (page 579) that it was desirable, when ropes were used in sequence to gearing, to keep up the rope speed and to make the gearing of steel; for if this were done, the backlash would not be prevented, and although the steel teeth might withstand the vibration, the other parts would suffer, such as the arms and bolts of the wheel and the shafts, to say nothing of the walls and foundations. The better plan was to prevent the backlash as much as possible, by reducing the energy of the ropes and rope drums.

In regard to pitch of teeth (page 579), he was ready to admit that the expressions "fine" and "coarse" pitch were misleading. What he really meant by a finely pitched wheel was a wheel having a large number of teeth. For heavy main driving gear he thought a wheel with less than fifty teeth might be described as coarse in pitch, a wheel with more than fifty and less than sixty as medium, and one with more than sixty as fine. As regarded the proper number of teeth to be adopted, he agreed with Mr. Saxon that it was impossible to lay down any hard and fast rule; and in the suggestions he had made he had no idea of doing so. All he desired to be understood was that as a general principle wheels with few teeth were not serviceable in heavy spur gearing. In this connection the recommendation made in page 544 of the paper might be qualified, in regard to the height of a tooth never exceeding half the pitch and in some cases being even less; this was not meant to be taken too literally, because of course there was no absolute relation between the height and the pitch of teeth. The proper height depended upon the absolute and relative diameters of the wheels, the speed of the pitch line, and the conditions of working. The recommendation was meant only as a protest against continuing to make teeth of a height equal to two-thirds or three-fourths of the pitch, as had been the custom formerly when gearing had an easier time of it than now.

As to what the speed of wheels should be (page 580), he could only advise that it should be as low as possible. For ordinary cast-iron wheels a circumferential speed of 2,000 feet per minute was quite enough; for cut steel wheels a higher speed might be adopted. He knew of a pair of the latter wheels running comfortably at 2,800 feet; but such speeds were not to be adopted by choice.

Manufacturers had replaced beam engines by long-stroke horizontal engines (page 585) because they were under the impression that a long stroke conduced to economy of steam, and a low speed of revolution to economy in repairs and to longevity. Of late years the speeds of mill shafting had gone up, and the speeds of engines had necessarily followed; hence shorter strokes and vertical engines had come into use.

The suggestion was not correct (page 586) that the breakages of Corliss valve-gear were few, because most of the engines from

(Mr. Longridge.)

which the examples in the paper had been drawn were of an early make, without Corliss gear. The inference (page 587) that the small number of breakages of Corliss gear pointed to the superiority of this gear was more in accordance with the facts. Speaking generally, the Corliss valves and the majority of the Corliss valve-gears now in use were the most satisfactory valves and valve-gears for large engines.

There was no need for an independent governor (page 589) for actuating a knock-off motion; nor was it necessary, if this motion were properly designed, to prop up the governor. If anything had to be propped it would be the runaway-valve, or some part of the expansion gear. But there was not the least necessity for any trouble of the kind, as the knock-off apparatus could easily be arranged so that it would not come into action when the engine was stopped by the driver.

The broken slide-bars (page 586) all belonged to engines which ran "outwards," that is, engines in which the pressure was on the bottom slide-bar.

He could not remember any instance of a piston having been broken by weakness at the cotter slot (page 589). The pistons of most factory engines were so strong that a good deal might be taken out of them without much risk. This view would be shared by all who had seen the pistons of the Willans engine.

Neither could he call to mind any instance of a steel crank having been damaged through being expanded by heating (page 589): though he felt great doubt about the effect produced upon the shaft when the hot crank was shrunk upon it. For this reason he thought it better to force cranks on by pressure than to heat them.

The President drew attention to the remarkable specimens exhibited by the author, which he thought were well worth careful examination by all present. They were greatly indebted to Mr. Longridge for the vast amount of time and trouble he must have devoted to the collection, classification, and criticism of the large number of breakdowns comprised in the paper: the object of which had not been to recommend any particular kind of design or any particular method of construction, but simply to illustrate the working conditions and defects of mechanism in the large manufacturing district with which his experience was so intimately associated. The whole paper he considered was most instructive, and should be highly useful to engineers generally. He was sure they were all most grateful to the author for the conspicuous care and ability with which he had dealt with this subject; and he invited them to join in according a hearty vote of thanks to Mr. Longridge for the great trouble he had taken on their behalf.

Mr. John G. Hudson wrote that an engineer in the author's position has exceptional opportunities of learning the weak points of steam engines, much greater even than has an engine builder, whose repairing work is principally limited to engines of his own make. Interesting and instructive as are the figures given in the paper, he ventures to suggest that they would be made still more valuable by the addition of a statement as to the period covered by the examples, the average number of the engines insured during that period, and a rough classification of their types and powers, with the proportion of the accidents proper to each. The bulk of the mishaps he believes would be found to have occurred to old-fashioned engines of small power; his own experience shows that breakdowns are so rare in modern mill-engines of large size that they may be almost neglected. The improvement in this respect is doubtless due to superior design and more skilful attendance, as well as to the substitution of the modern direct-acting self-contained rope-driving engine, for the slow-speed gear-driving beam-engine, which trusted principally to the buildings and foundations for its support; and the improvement has been realised, notwithstanding the fact that the speed of running has been greatly increased. Of the few serious accidents occurring to modern engines, a large proportion are probably accounted for by water getting into the cylinder; and such accidents usually cause extensive damage. Broken crank-shafts used to be the cause of many serious breakdowns; but since the adoption of Siemens-Martin steel these have practically disappeared; in fact, since the adoption

(Mr. John G. Hudson.)

of this material by Messrs. Hick, Hargreaves and Co. some ten to twelve years ago, they have never known one of these crank-shafts to fail, though such failures were formerly common enough with crank-shafts of wrought-iron and Bessemer steel. Their Siemens-Martin steel shafts have almost without exception been forged at the Bolton Iron and Steel Works, and for many years they have made a practice of boring each shaft from end to end, in order to ascertain the soundness of the interior. This boring has in many instances resulted in the rejection of shafts as defective, which would have passed as perfect if judged only by their exterior.

The conclusion to which the writer's experience leads him is that the vast majority of breakages are due either to transverse strains or to vibration, and rarely indeed to a fair direct tensile or compressive stress. The moral is that overhang should be avoided when practicable, or be reduced to a minimum and liberally provided for when inevitable. Many old engines are shocking examples in this respect, the crank-pin having a deep collar next the crank, and the crank having a deep boss on the shaft, while the gap still remaining between the crank-boss and the crank-neck is often utilised for a pulley driving the governor.

Messrs. Woodhouse and Mitchell, of Brighouse, wrote that, of the breakdowns originating with pistons (page 566), it was stated that nearly half were due to junk-ring or cover bolts getting loose or breaking. Though a small matter, this is one of practical importance, in regard to which mechanical engineers have not hitherto been at all satisfied. For preventing such screws from working loose, they suggest the use of the compound locking washer shown in Fig. 109, Plate 135, which consists of two washers, one upon the other; the lower *w* is of ordinary strength, and the upper *t* is thin pliant metal. Both are made with indentations on the upper side and corresponding projections on the under; the projections under the lower washer fit into corresponding indentations in the junk-ring, and the projections under the upper washer fit into the indentations in the lower; the washers themselves are thereby prevented from turning. When the screw has been tightened up, the rim of the upper washer is turned up, as shown dotted at *r*, against one or more sides of the screw head, thereby locking it. This makes a neat and safe job.

Mr. Longridge wrote that the period within which the thousand breakdowns dealt with in the paper had occurred (page 593) was nearly eight years; but without a tedious investigation it was not possible to state the average numbers and powers of engines of different kinds insured during this period.

The bulk of the mishaps did not occur to small engines. Doubtless old engines broke down rather more often than new, because they had not been so well designed, and were often much more heavily burdened; but it would be quite contrary to the experience of insurance companies to say that the breakdowns of modern mill-engines were so rare that they might be almost neglected. Nor was it their experience that a large proportion of the breakdowns of modern mill-engines were due to water in the cylinders. Such engines generally had Corliss valves, and well pipes or separators to keep water out of the cylinders; and they ran much less risk in respect of damage from water than many of their predecessors.

The substitution of Siemens-Martin steel for iron and Bessemer steel had undoubtedly accounted for a large reduction in the number of broken main-shafts; but the great increase in the factor of safety adopted of late years had also had an important influence.

Some satisfactory means of securing piston bolts was much needed; and he was glad to learn the method suggested by Messrs. Woodhouse and Mitchell (page 594) for accomplishing this object.

MEMOIRS.

Frank Ashwell was born in Nottingham on 25th May 1855. After being educated at the High School he entered the works of Messrs. Manlove, Alliott and Co., as a pupil in 1872. Having passed through the various departments, he went in 1877 to the works of Messrs. Caird and Co. of Greenock, where he remained two years. In 1879 he commenced business on his own account in Leicester, as a manufacturer particularly of warming and ventilating appliances for use in public buildings, of which a large number were so fitted up by him in various localities, including asylums, municipal and county buildings, banks and schools. In 1891 he took into partnership Mr. D. M. Nesbit, who had been manager since 1883 of the warming and ventilating department. A London branch of the business was opened in 1891, and other branches afterwards in Nottingham, Newcastle-on-Tyne, and Dublin. In sixteen years the works in Leicester had grown to the extent of employing 250 hands. His death took place at Leicester on 4th December 1896, at the age of forty-one. He became a Member of this Institution in 1884.

Robert William Peregrine Birch was born in London on 25th September 1845. After being educated at King's College, London, he became in 1864 a pupil of the late Mr. James Abernethy, under whom he was employed upon important works, and was for some time a member of the engineering staff constructing the Swansea Docks. On leaving Mr. Abernethy he became resident engineer on the Thetford and Watton Railway under Mr. J. S. Valentine. In 1870–71 he designed and carried out the drainage of Walton-on-Thames on the intermittent downward filtration system. This was one of the earliest applications of this method of sewage disposal, and was highly successful; but as the area of ground acquired for the purpose was surrounded by land suitable for broad irrigation, the original plan was abandoned in favour of the latter as less troublesome and more profitable. Having started business in Westminster as a consulting engineer, he became joint author with the late Mr. William Haywood of a scheme for the sewerage of the Lower Thames Valley. He was next connected with the enquiry into the pollution of the Thames by the sewage of London. Together with Mr. James Mansergh and Mr. Baldwin Latham he was employed by the City Corporation in 1882 to lay before the Royal Commission on Metropolitan Sewage Discharge the case against the late Metropolitan Board of Works, with the result that the chemical treatment of the sewage was effected before its discharge into the river. He frequently acted for the London Water Companies in their dealings with the London County Council. Though best known as a hydraulic and sanitary engineer, he was also connected with railway work, being associated with Sir J. Wolfe Barry, K.C.B., and Mr. Brunel as engineers to the Guildford, Kingston and London Railway; and in conjunction with Professor Henry Robinson he was engineer to the Wimbledon and Putney Railway. Recently he had made an important extension of the pier at West Brighton. His death took place on 30th August 1896 in his fifty-first year, from erysipelas of the face after a few days' illness at Foyers, Scotland, while on a visit to the water-power works he was carrying out for the British Aluminium Co. He became a Member of this Institution in 1877; and was a Member of Council of the Sanitary Institute and of the Royal Meteorological Society, and also a Member of the Institution of Civil Engineers.

Frederick Heathcote Carter was born in Manchester on 27th February 1855. From 1873 to 1882 he was engaged with Messrs. Measures Brothers and Co., London, assisting in designing and in superintending the construction and erection of roofs, girders, and other structural ironwork. From 1882 to 1886 he was in partnership with his brother in Manchester; and subsequently carried on business for himself as contracting engineer for work constructed and erected under his superintendence. His death took place at Bowdon, Cheshire, on 10th October 1896, in his forty-second year. He became an Associate of this Institution in 1891.

George Manners Dickson was born in 1844. In 1857 he entered Messrs. James Watt and Co.'s Soho Works, Birmingham, and there served an apprenticeship of seven years till midsummer 1864. During 1865 he was engaged in erecting and repairing engines at Fleetwood, Preston, Leeds, and Birmingham; and during the next two years erected pumping machinery at Novo Tcherkask, Russia, for which he received a silver medal for ability from the Emperor. In December 1867 he went to Calcutta, where he erected large pumping engines and machinery, of which he had charge until 1887, when he was promoted to the position of assistant engineer to the Calcutta Water Works. His death took place at Calcutta on 8th August 1895, at the age of fifty-one. He was elected a Member of this Institution in 1888.

James Henry Greathead was born at Grahamstown, Cape Colony, on 6th August 1844. In 1859 he came to England for the completion of his education; and in 1864 commenced a pupilage of three years under the late Mr. Peter W. Barlow. On its expiration, he was engaged for a year as an assistant engineer upon the construction of the Midland Railway extension from Bedford to London, under Mr. W. H. Barlow and Mr. C. B. Baker. In 1869 he was entrusted with the construction of the Tower Subway under the river Thames; and for this work he adopted a cylindrical wrought-iron shield, forced forwards by six powerful screws as the material was excavated in front of it. The subway was completed in the same year; and in 1870 he began to practise on his own account as consulting engineer. In 1873 and for the four following years he acted as resident engineer on the Hammersmith Extension Railway and the Richmond Extension of the Metropolitan District Railway. He assisted in the preparations for several other projects, namely the Regent's Canal Railway in 1880, the Dagenham Dock and the Metropolitan Outer Circle Railway in 1881, a new line between London and Eastbourne in 1883, and various Irish light railways in 1884. In the latter year he was engaged on the preparation of the bill for the City and South London Railway. The work was commenced in October 1886, and the line was opened in November

1890 by the Prince of Wales. During the construction of this line compressed-air was employed to prevent the inrush of water; and the success of this plan led to its adoption in other similar enterprises in which he was engaged. He invented apparatus for the application of water to excavate in front of the shield, and for injecting cement-grout behind the lining of the tunnel. In 1888 he became joint engineer with Sir Douglas Fox for the construction of the Liverpool Overhead Railway, which was visited by the members of this Institution on the occasion of the Liverpool Meeting in 1891. He was engaged as joint engineer with Mr. W. R. Galbraith on the Waterloo and City Railway; and on the Central London Railway he was associated with Sir John Fowler and Sir Benjamin Baker. He did not live to see the completion of these undertakings, his death taking place at Streatham on 21st October 1896, at the age of fifty-two. He became a Member of this Institution in 1879; and was also a Member of Council of the Institution of Civil Engineers.

William Hindson was born at Cummersdale, near Carlisle, on 13th February 1846. In 1860 he commenced an apprenticeship in the shops and drawing office of Sir W. G. Armstrong and Co., Elswick, and remained there till 1872, when he went to the works of Messrs. John Abbot and Co., Gateshead. There he remained for twenty-one years, during the last twelve of which he was works manager. The work he was particularly interested in was the design of hydraulic machinery; and during that period a large number of hydraulic contracts were carried out, notably for King's Lynn Docks, Newcastle Grain Warehouse, Wellington (N.Z.) Harbour Board, Melbourne Hydraulic Power, Sydney Hydraulic Power, and others. He devised a stockless anchor for Messrs. Abbot, and a self-locking railway chair known by his own name. In November 1893 he commenced business on his own account, taking over the existing portion of Messrs. Hawks, Crawshay and Co.'s Works at Gateshead. He took an active interest in local affairs, and in 1893 was elected a member of the Gateshead Town Council. His death took place after a short illness at Whitley, Northumberland, on 7th July 1896, at the age of fifty. He became a Member of this Institution in 1887.

JAMES IBBS LAWSON was born at Ulverston, Lancashire, on 7th February 1861. His early education was received at the Merchant Taylors' School, Great Crosby, near Liverpool. In 1872 he went with his parents to New Zealand, where his education was continued at Christ's College, Christchurch. In 1876 he was articled to Mr. Charles Napier Bell; and on the expiration of the term in 1881 he entered the service of the government railway department, subsequently becoming assistant engineer of the Southland district in 1886, and resident engineer in 1888. In April 1889 he went in the latter capacity to the Wellington district, returning to Southland in December of the same year. In December 1891 he was transferred to the Auckland district, and finally in May 1892 to the Napier-Taranaki district, in which he had charge of 407 miles of railway. His death occurred on 2nd July 1896, at the age of thirty-five, from the result of an accident. In company with Mr. Lowe, the engineer-in-chief, he was inspecting the permanent line, which had been damaged by floods, and when the train was approaching the long Pohangina Bridge he leaned forward on the platform of the carriage to see the track. Looking backwards he was killed by his head striking an iron girder of the bridge, and he was hurled into the river below. His remains were recovered in January 1897, over six months after the accident. He became a Graduate of this Institution in 1881; and was also an Associate Member of the Institution of Civil Engineers.

GEORGE LITTLE was born in Leeds on 12th July 1823. After serving his apprenticeship he went to Oldham, and obtained employment with the firm of Messrs. Hibbert and Platt, where he rose to the successive positions of foreman, manager, director, and managing director. During the period of fifty-two years he introduced many labour-saving machines, more particularly those connected with planing, shaping, boring, turning, and wood-working; also arrangements for plate and plaster moulding, and for lifting and moving boxes in foundries. He was specially associated with the worsted and combing departments, in relation both to cotton, wool, and silk; and took a leading part in designing and constructing worsted machinery for working wool on the French system. As a supporter of technical education he took an active interest in the Werneth Mechanics' Institute, of which he was one of the earliest members, and at one time president. A few years ago his health gave indications of failing, and he removed to Southport, still continuing to take his share as a director in the management of the business. His death took place at his residence in Southport on 24th July 1896, at the age of seventy-three. He became a Member of this Institution in 1866.

Peter McGregor was born at Kippen, Stirling, on 19th March 1860. He served an apprenticeship with Messrs. John McAllum and Co., Stirlingshire, from 1875 to 1880, spending two years in the fitting shop, two years in the pattern shop, and one year in the drawing office. In 1880 he entered the employment of Messrs. J. and G. Thomson, engineers and shipbuilders, Clydebank, Glasgow, for two years as a pattern-maker and one year as a fitter. In 1883 he entered the service of the Clan Line of steamers sailing to India, and served successively as fourth, third, and second engineer until 1887, when he received an appointment in the Imperial Chinese Customs service as second engineer of the revenue steamer "Li Kin." On 1st April 1896 he became acting first engineer of the Chinese revenue cruiser "Kaipan." His death took place in Hong Kong from cancer in the throat, on 1st October 1896, at the age of thirty-six. He became a Member of this Institution in 1892.

William Charles Stiff was born at Leamington on 1st September 1836. He was at one time engaged at The Brades Steel Works near Birmingham; and commenced his engineering work in 1863, and since that time had been engaged in designing and manufacturing machinery for making gun-barrels and cold-drawn weldless steel-tubes. In this direction he began by experimenting upon some original machinery for the manufacture of weldless steel-tubes, which had been abandoned as useless; and by his energy and ability the difficulties connected with the process were ultimately surmounted, and cold-drawn weldless steel-tubes, now so extensively used for cycles and for boilers of torpedo boats and their destroyers, were successfully manufactured and introduced. He established the Credenda Seamless Steel-Tube Works at Smethwick, near Birmingham, of which he was the managing director. His death took place at his residence in Edgbaston, Birmingham, from syncope, on 6th June 1896, in his sixtieth year. He became a Member of this Institution in 1888.

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VALUE OF STEAM-JACKET.

Express Passenger Locomotive, L. and Y. Railway.

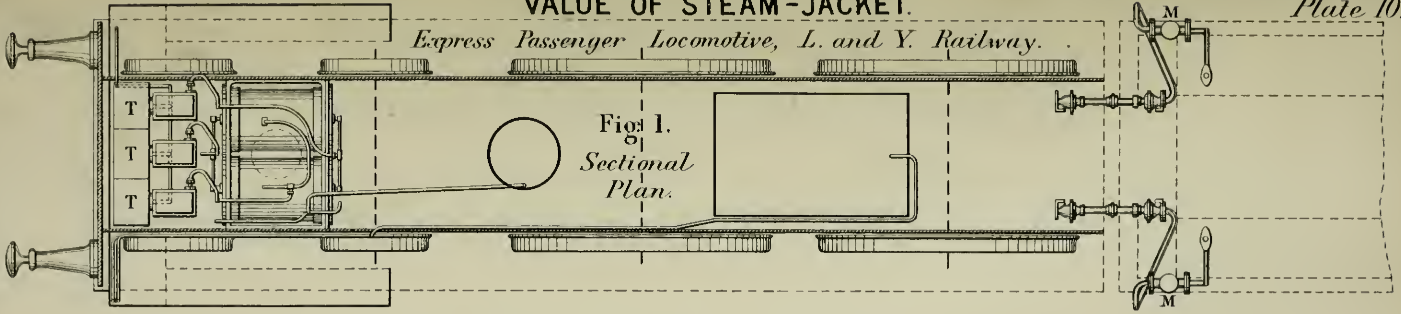


Fig: 1.
Sectional Plan.

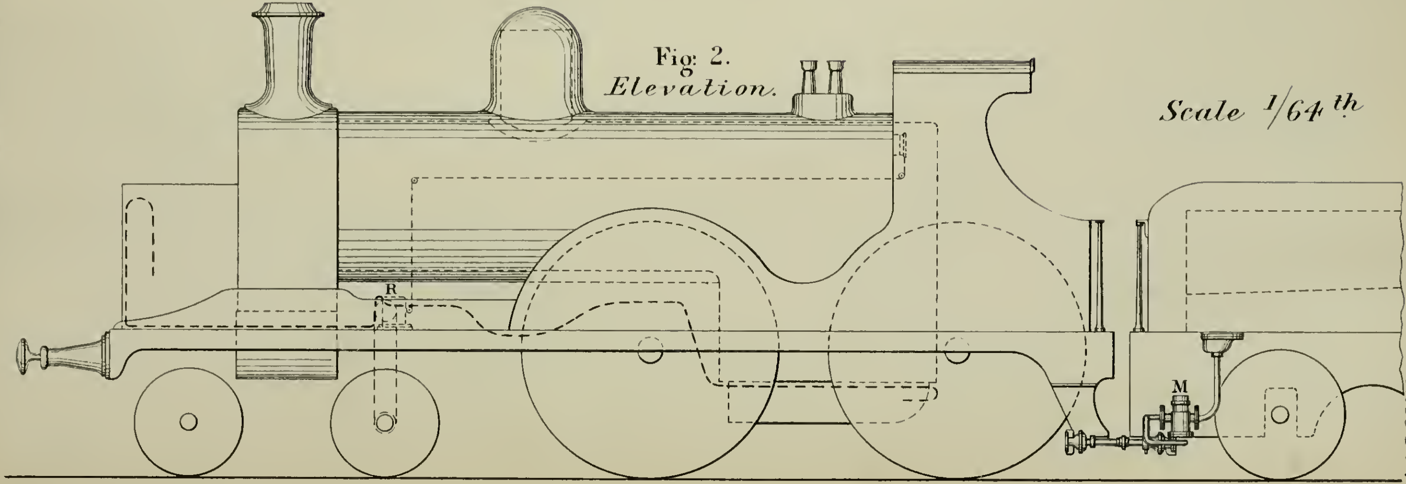


Fig: 2.
Elevation.

Scale 1/64th

VALUE OF STEAM-JACKET.

Express Passenger Locomotive,

Lancashire and Yorkshire Railway.

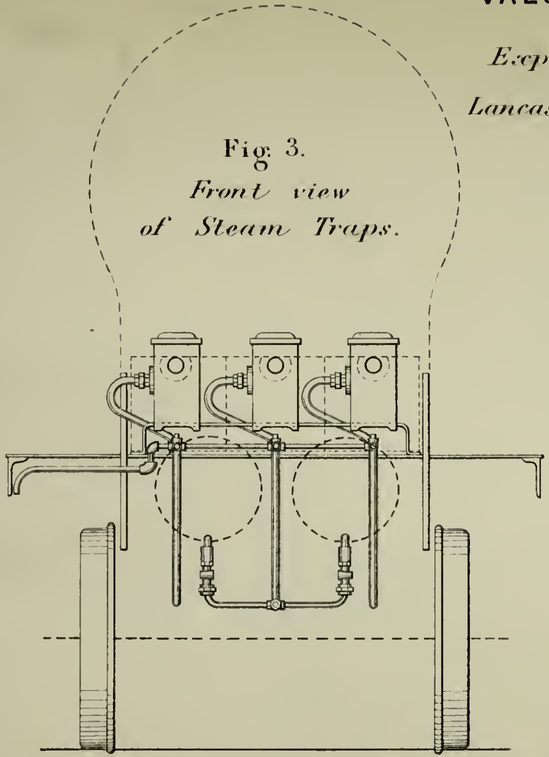


Fig. 3.
Front view of Steam Traps.

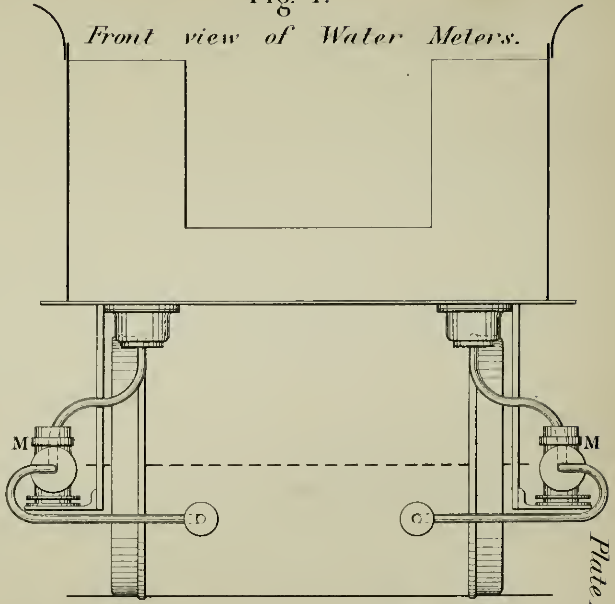
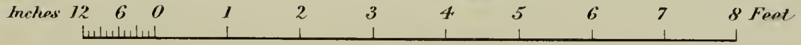


Fig. 4.
Front view of Water Meters.

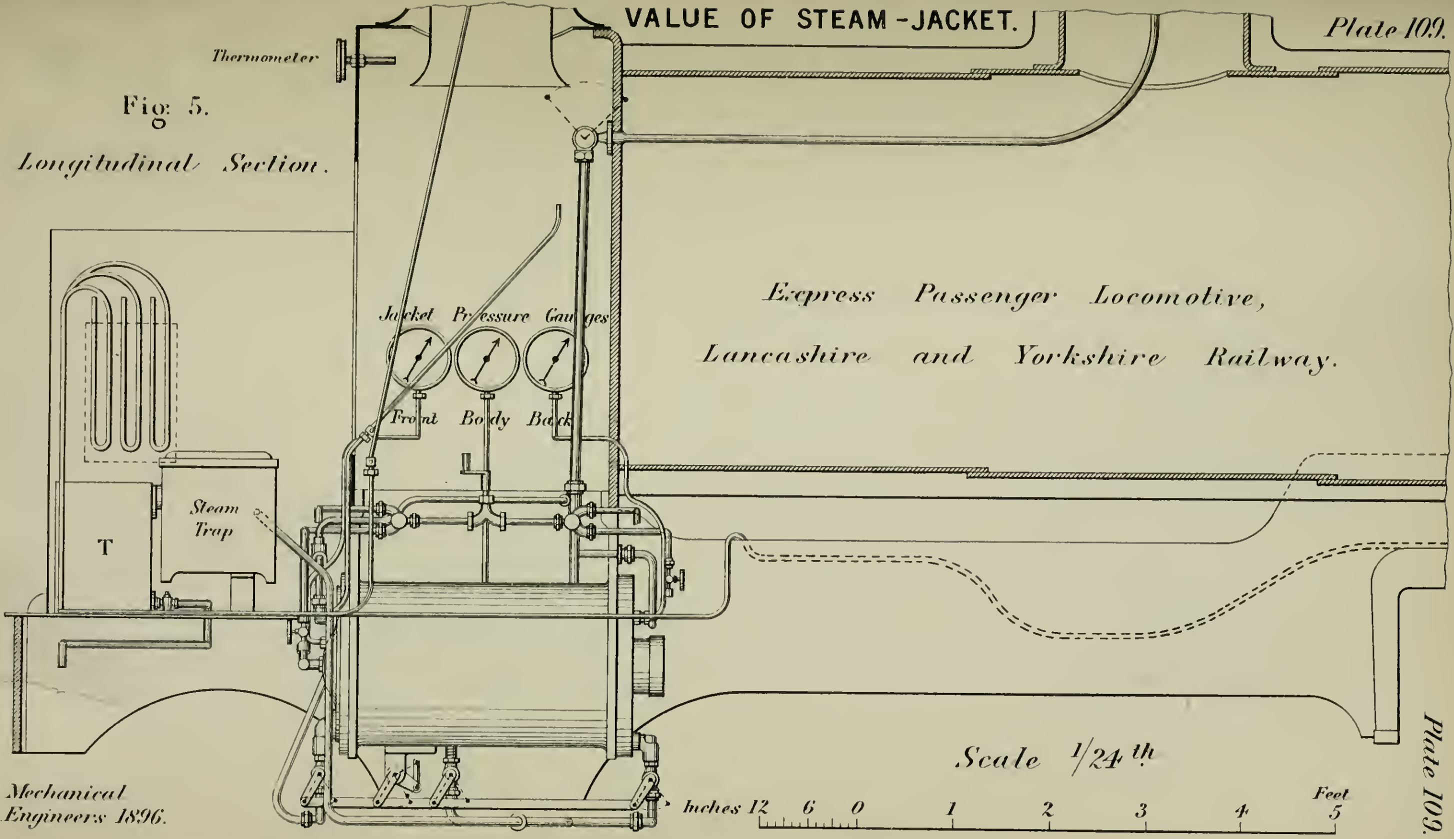
Scale 1/32nd.



VALUE OF STEAM-JACKET.

Fig: 5.

Longitudinal Section.



Express Passenger Locomotive,

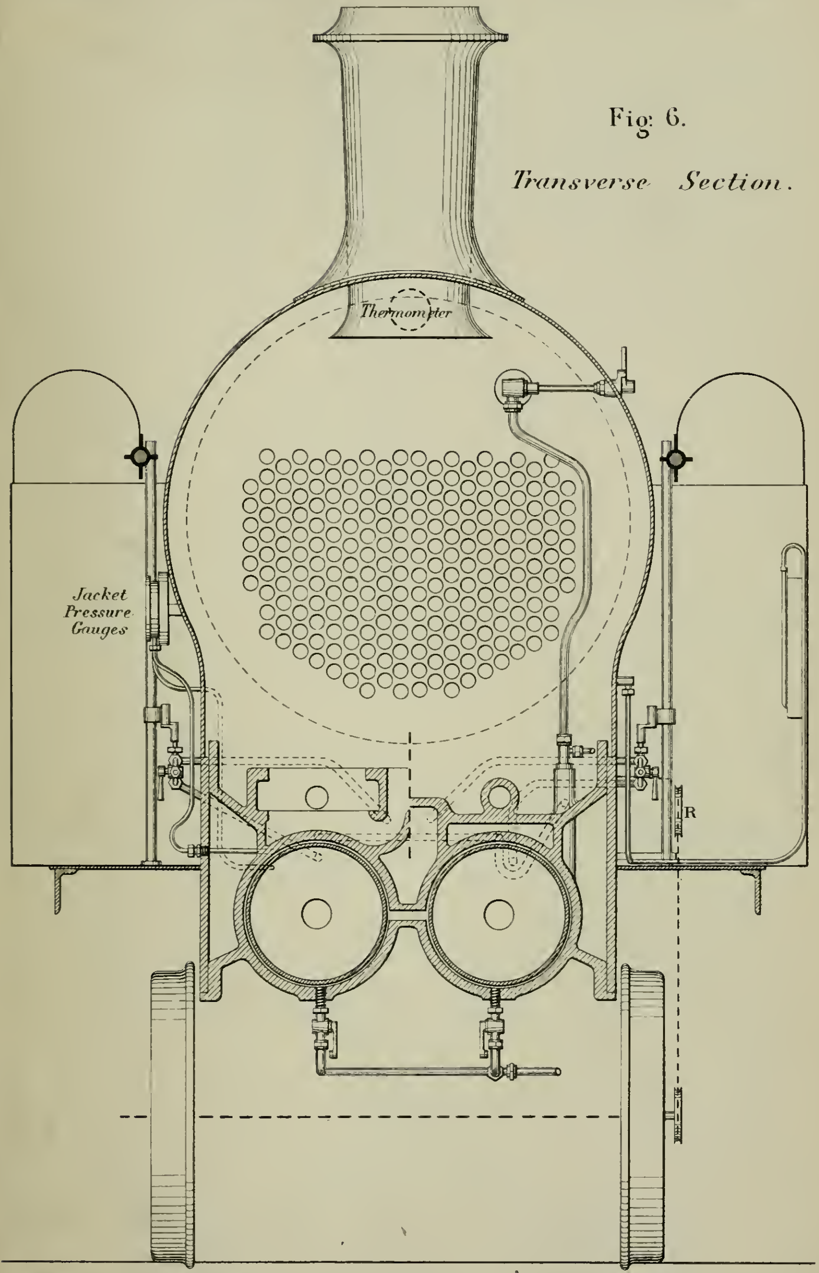
Lancashire and Yorkshire Railway.

VALUE OF STEAM-JACKET. *Plate 110.*

Express Passenger Locomotive, L. and Y. Railway.

Fig: 6.

Transverse Section.



Mechanical Engineers 1896. *Scale 1/24th.*

VALUE OF STEAM-JACKET.

Plate III.

Cylinders.

Fig. 7. *Sectional Plan.*

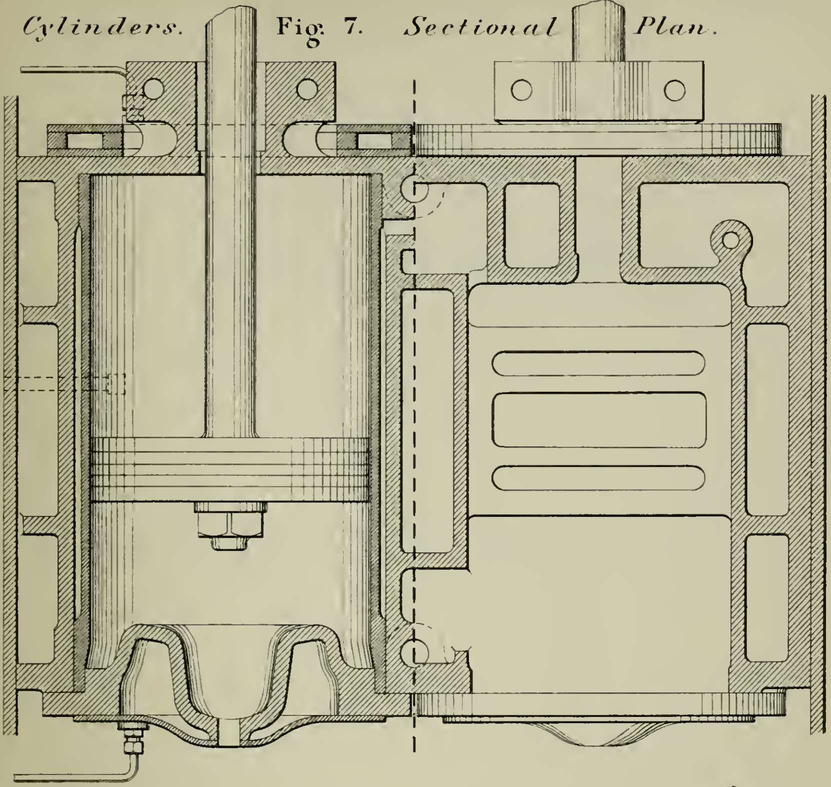
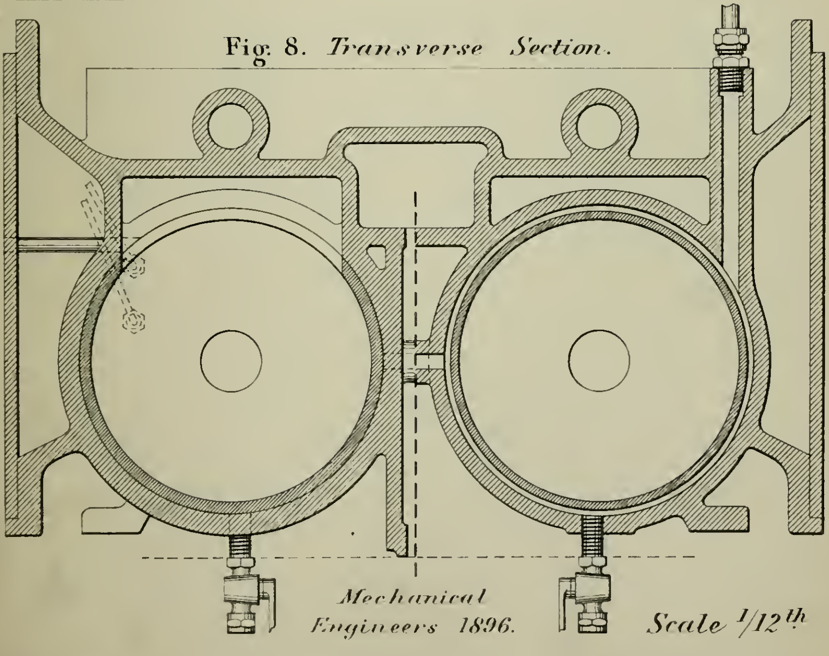


Fig. 8. *Transverse Section.*



Mechanical Engineers 1896.

Scale 1/12th

VALUE OF STEAM-JACKET.

Cylinder.

Fig: 9. *Longitudinal Section.*

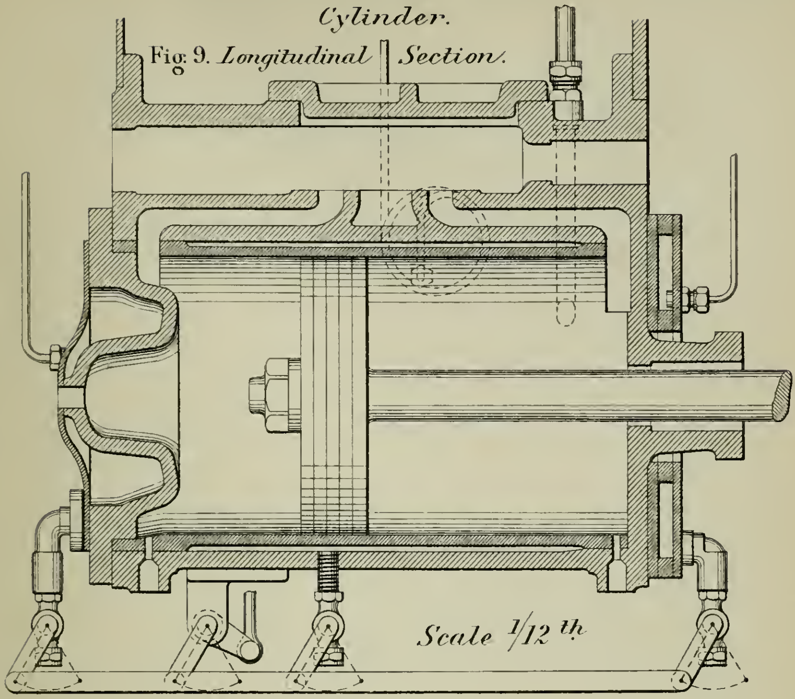
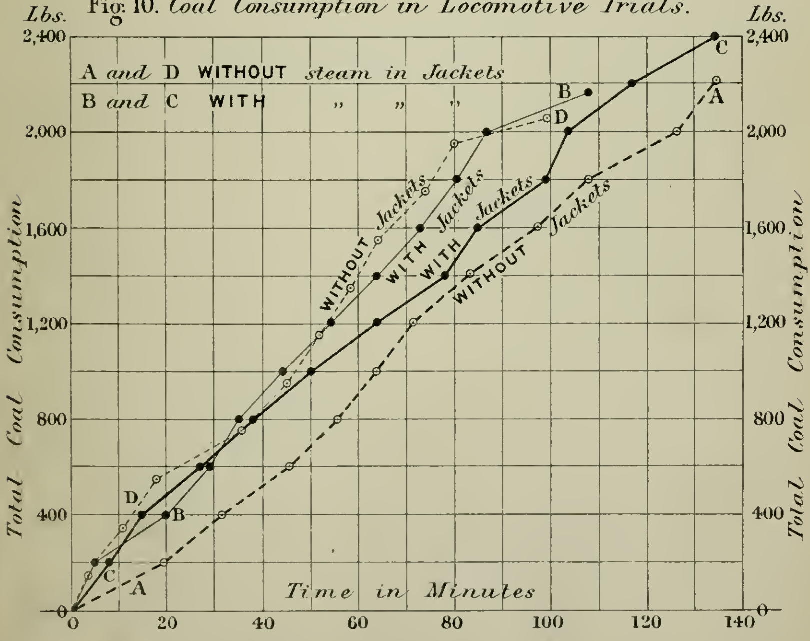


Fig: 10. *Coal Consumption in Locomotive Trials.*



VALUE OF STEAM-JACKET. *Plate 113.*

Express Passenger Locomotive Engine, L. and Y. Ry.

Indicator Diagrams nearest mean.

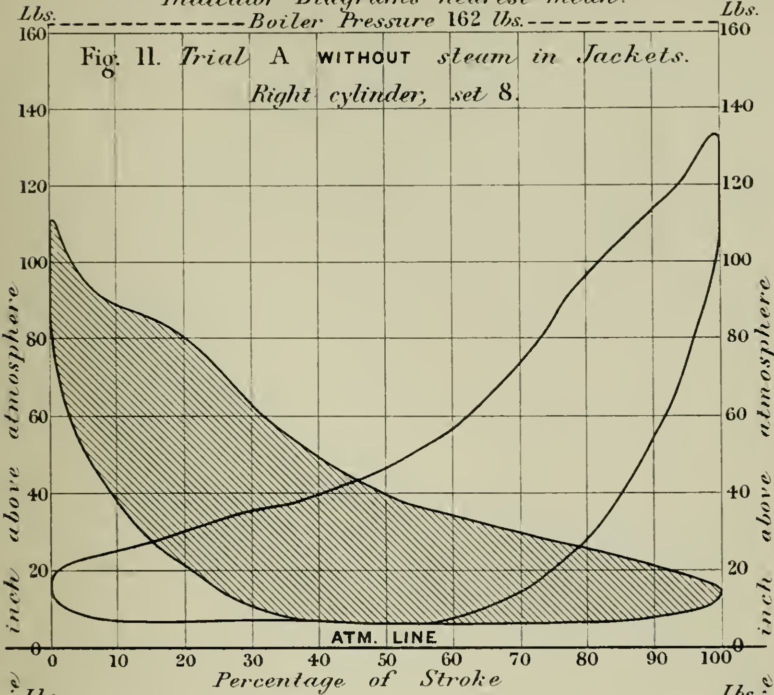


Fig. 11. *Trial* A WITHOUT *steam in Jackets.*
Right cylinder, set 8.

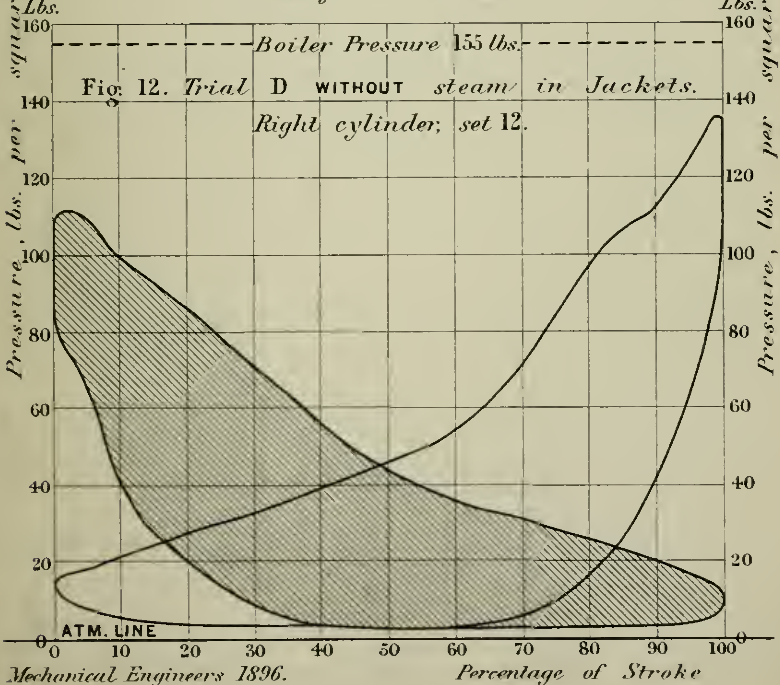


Fig. 12. *Trial* D WITHOUT *steam in Jackets.*
Right cylinder, set 12.

Mechanical Engineers 1896.

VALUE OF STEAM-JACKET.

Express Passenger Locomotive Engine, L. and Y. Ry.
Indicator Diagrams nearest mean.

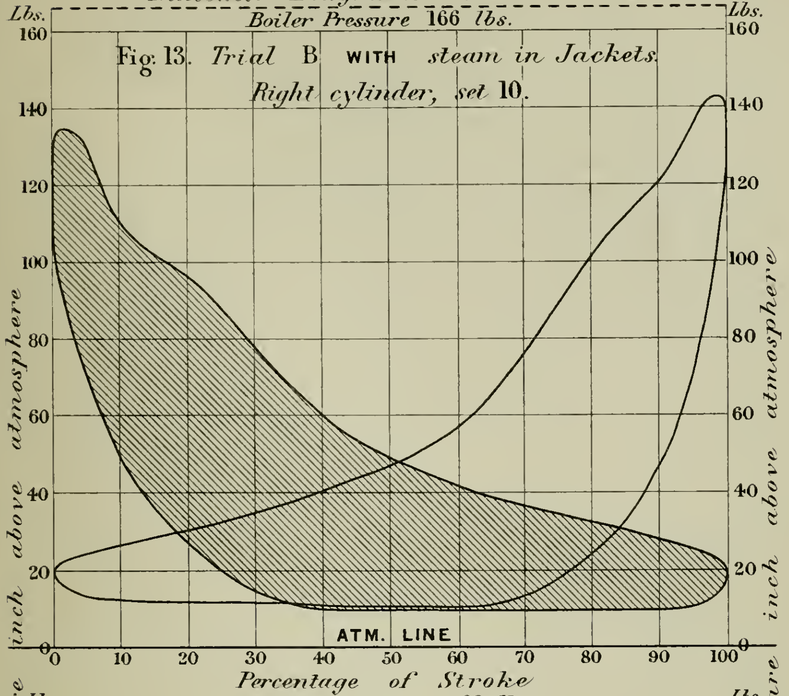


Fig: 13. *Trial* B WITH *steam in Jackets.*
Right cylinder, set 10.

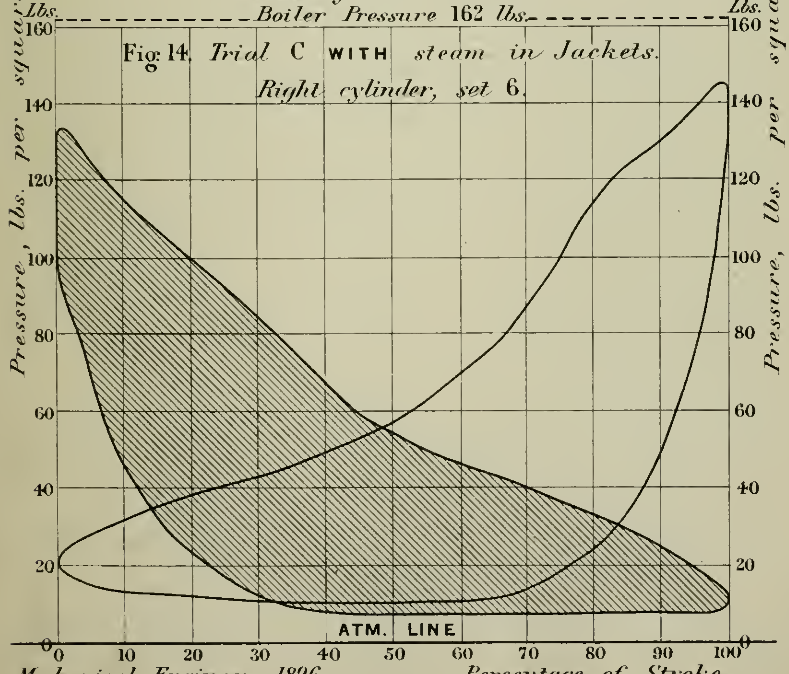


Fig: 14. *Trial* C WITH *steam in Jackets.*
Right cylinder, set 6.

VALUE OF STEAM-JACKET.

Fig: 15. *Speed, miles per hour.*

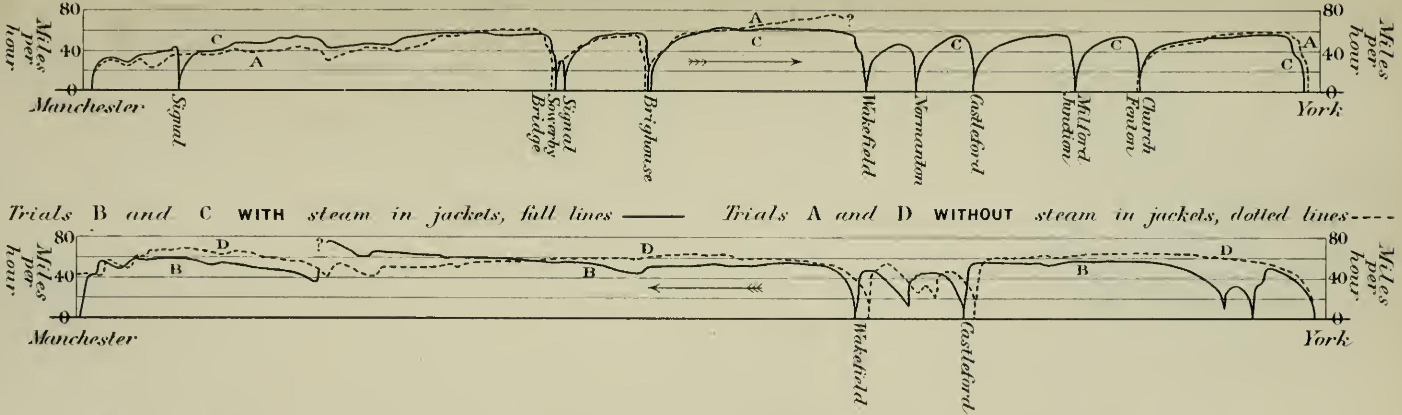
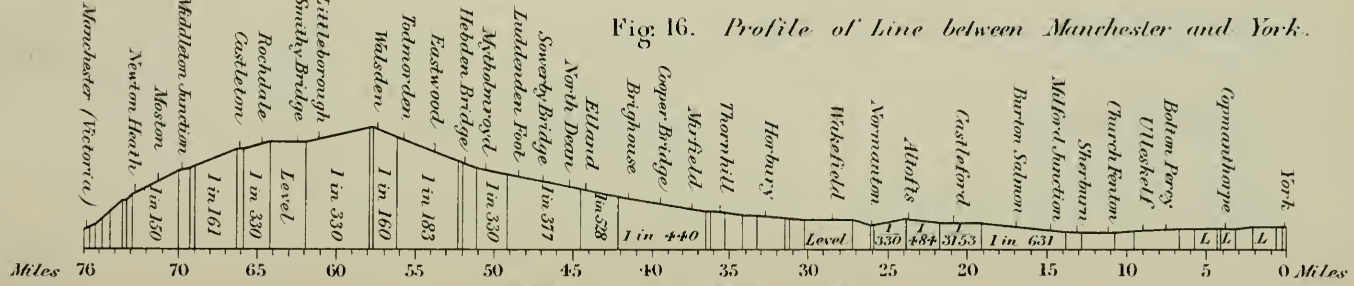

Trials B *and* C **WITH** *steam in jackets, full lines* ——— *Trials* A *and* D **WITHOUT** *steam in jackets, dotted lines* - - - -

Fig: 16. *Profile of Line between Manchester and York.*



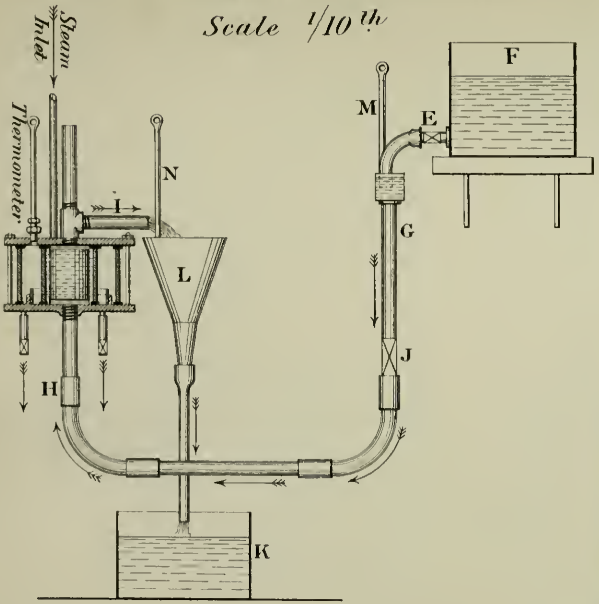
Mechanical Engineers 1896.

HEAT TRANSMISSION.

Fig: 1.

General Arrangement of Apparatus.

Scale 1/10th



Series 1.

Fig: 2.

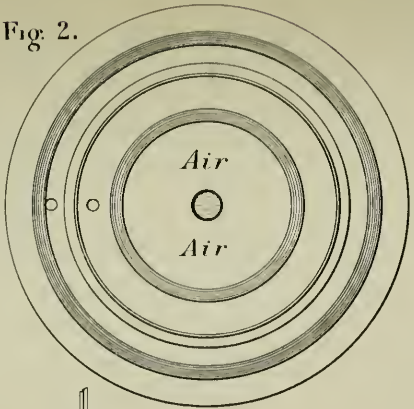


Fig: 4.

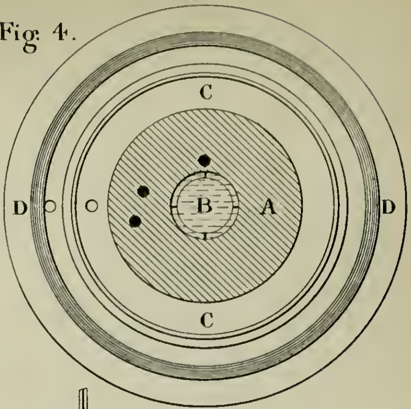


Fig: 3.

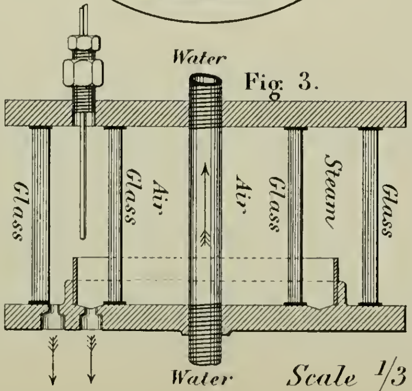
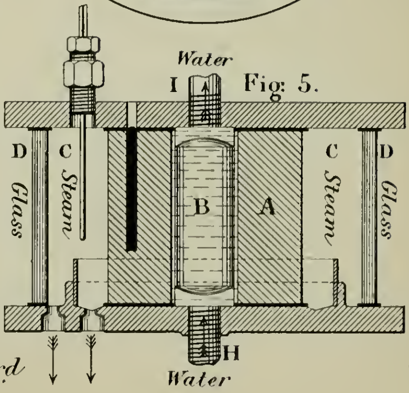


Fig: 5.

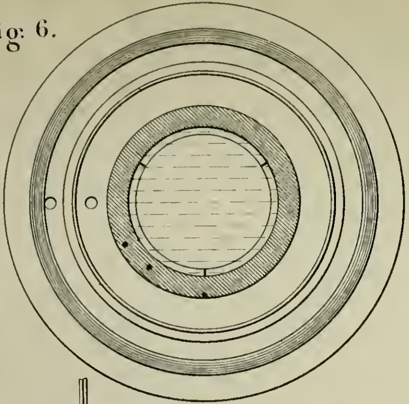


Scale 1/3rd

HEAT TRANSMISSION.

Series 2 and 4.

Fig: 6.



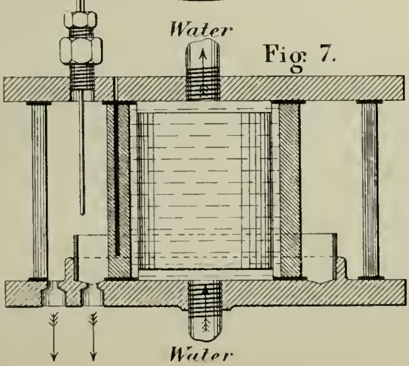
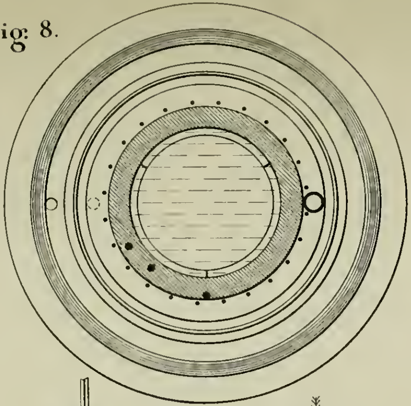


Fig: 7.

Series 3 and 5.

Fig: 8.



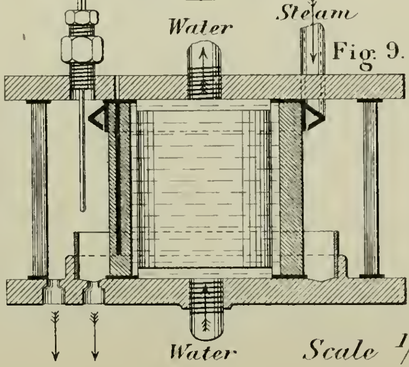
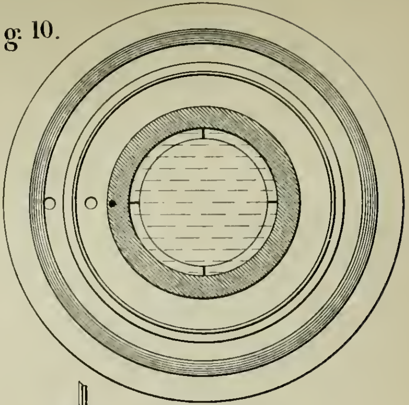


Fig: 9.

Series 6.

Fig: 10.



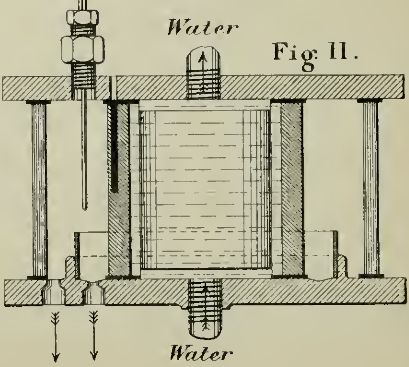


Fig: 11.

Scale 1/3rd

HEAT TRANSMISSION.

Series 7.

Fig. 12.

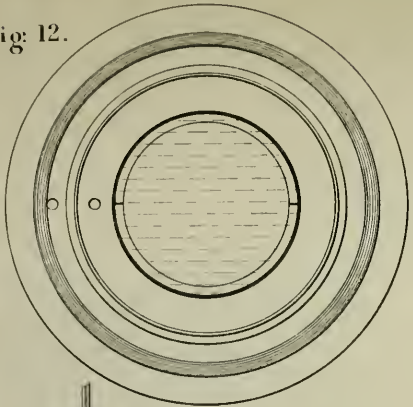
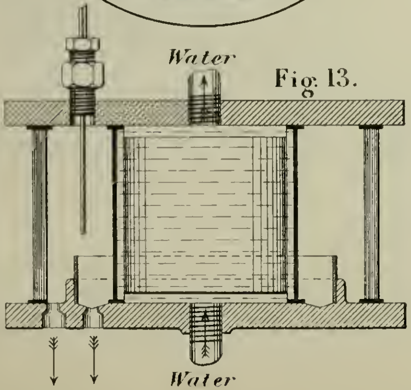


Fig. 13.



Series 8.

Fig. 14.

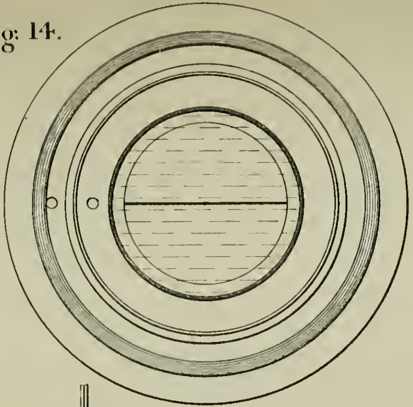
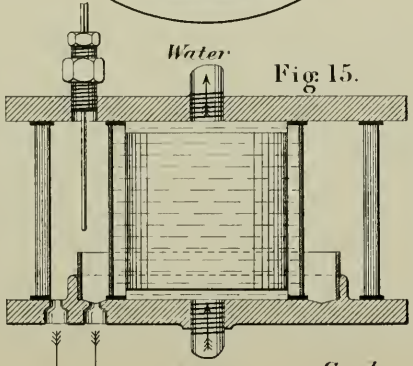


Fig. 15.



Series 9.

Fig. 16.

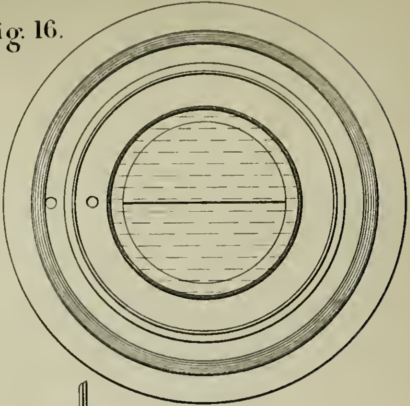
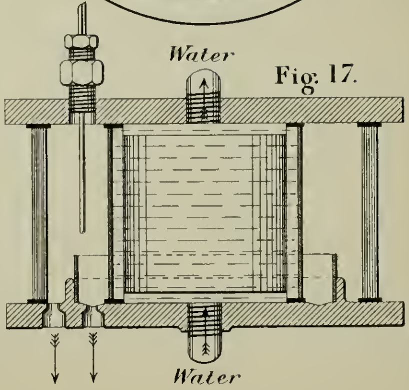


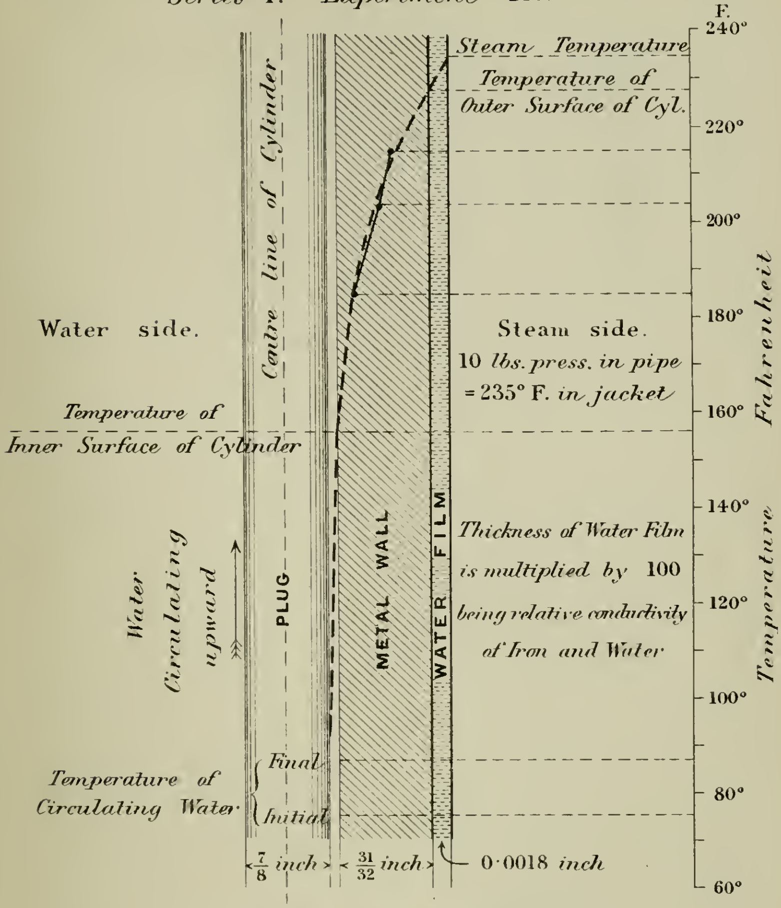
Fig. 17.



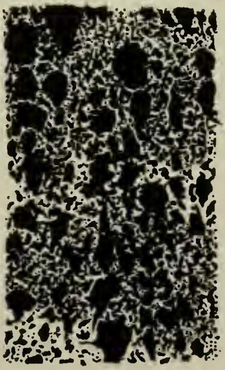
Scale $^1/_3$ rd

Fig. 18. *Thermal Gradient through Cast-iron Cylinder Wall.*

Series 1. *Experiment* 210.



Film of Water condensed on surface of Smooth Cast-Iron.



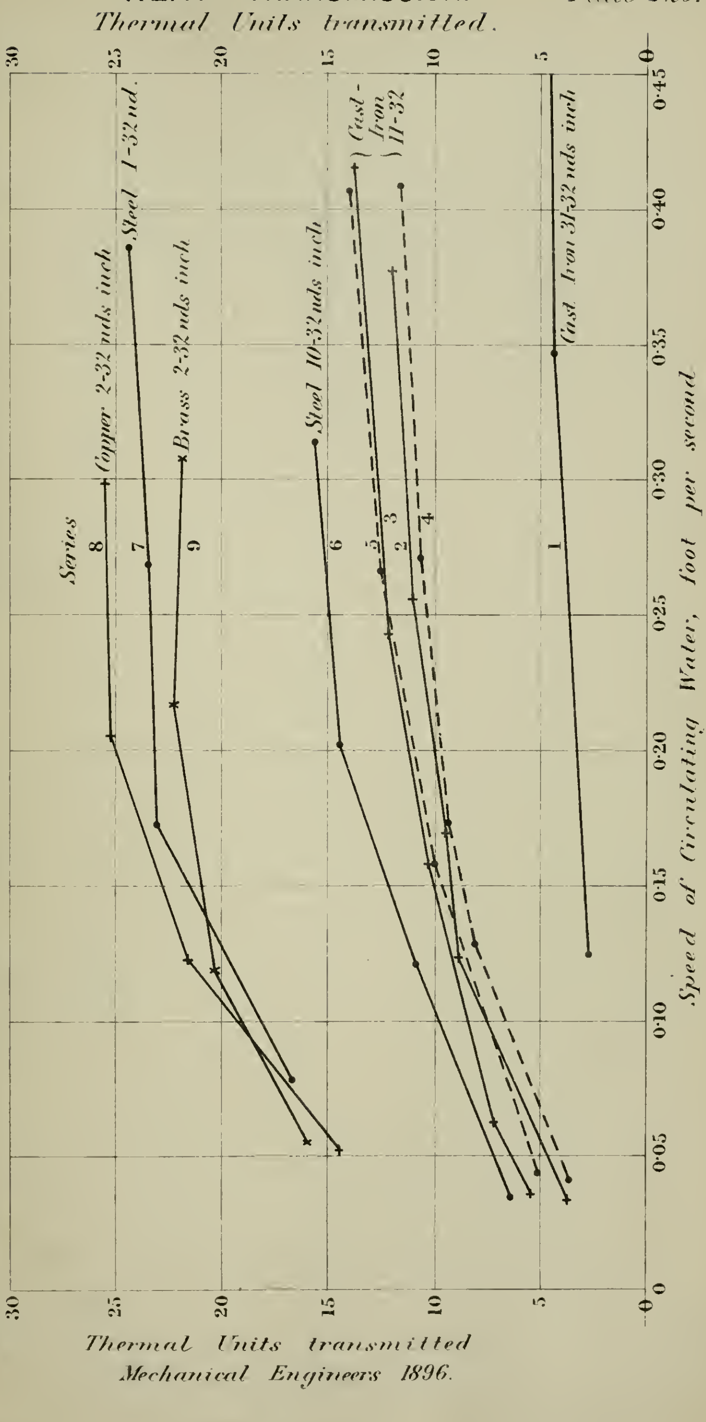
Full size.

Fig. 19.

Fig. 20. Heat transmitted per second per square foot of External surface of Metallic Cylinder. Plate 120.

Pressure of Steam in jacket 10 lbs. per square inch by gauge.

Metal Smooth on both sides, full lines —— Metal Rough on both sides, dotted lines - - -



Mechanical Engineers 1896.

Plate 121.

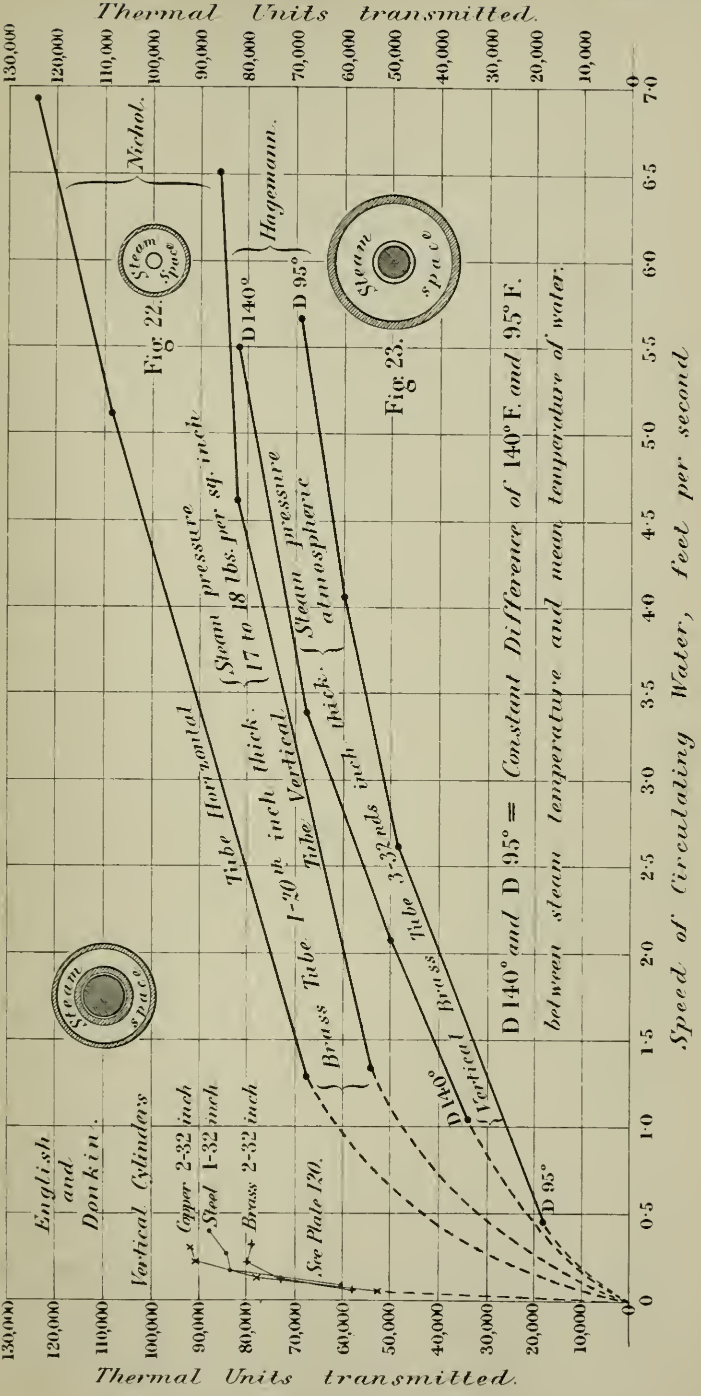
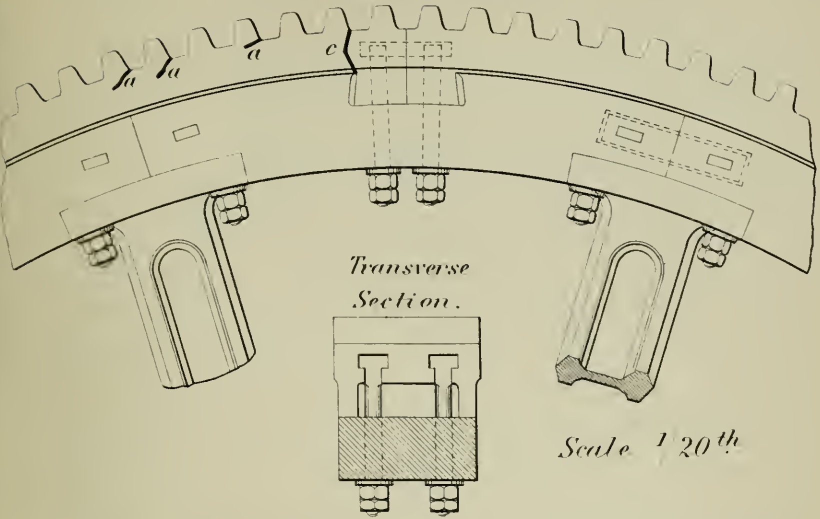


Fig. 21. *Heat transmitted per hour per square foot of surface of Brass Tubes &c.*

Mechanical Engineers 1896.

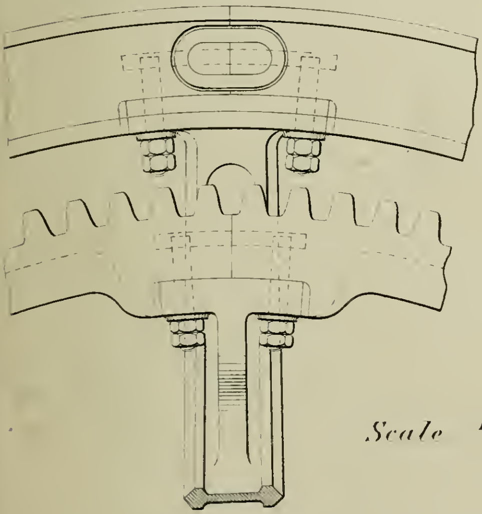
Fig: 1. *Spur Gearing.*



Transverse Section.

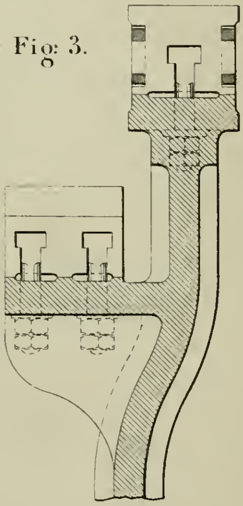
Scale 1/20th.

Fig: 2. *Elevation.*



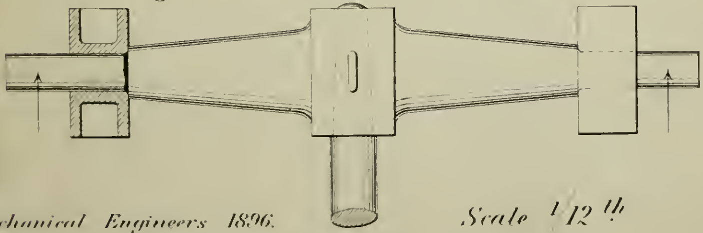
Transverse Section.

Fig: 3.



Scale 1/20th.

Fig: 4. *Air-Pump Cross-head.*



Scale 1/12th.

Air-pump-rod Cotters.

Fig: 5.

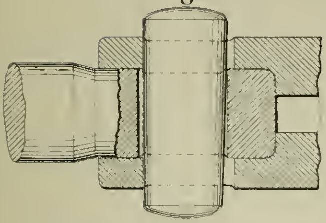
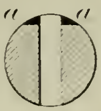


Fig: 6.



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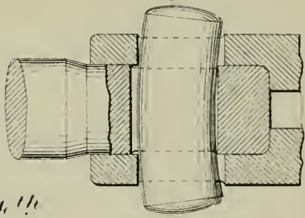


Scale 1/4th

Fig: 8.

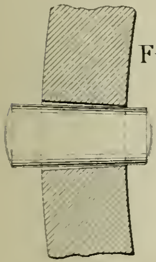


Fig: 9.

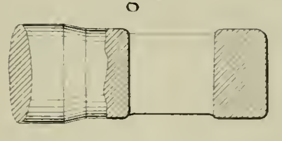


Fig: 10.

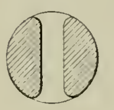
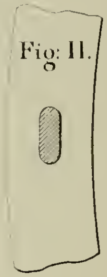


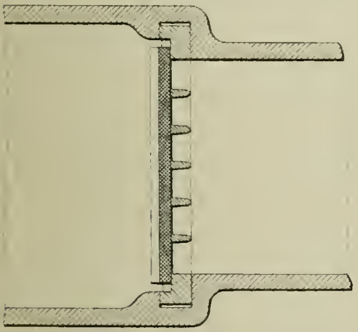
Fig: 11.



Scale 1/4th

Air-pump Foot-valve.

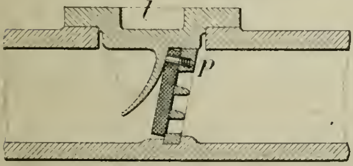
Fig: 12. *Sectional Plan.*



Scale 1/12th

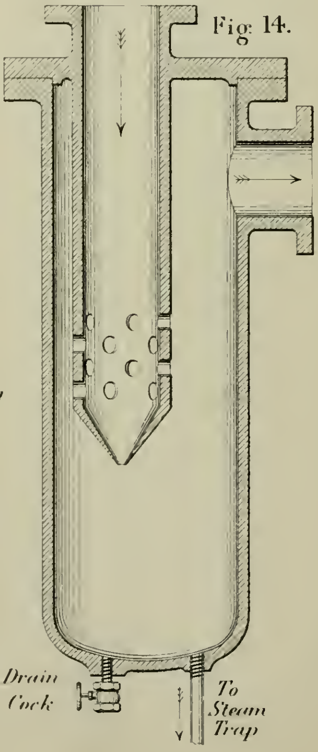
Fig: 13.

Sectional Elevation.



Steam Separator.

Fig: 14.



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STEAM-ENGINE BREAKDOWNS. *Plate 134.*

Main Shafts, 37 Fractured in Neck. Table 9.

Fig. 15.

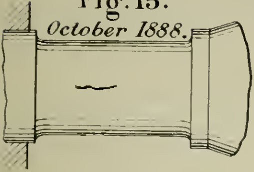


Fig. 15 *a*.

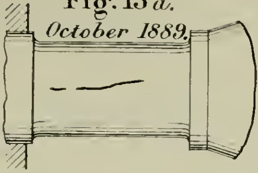


Fig. 15 *b*.

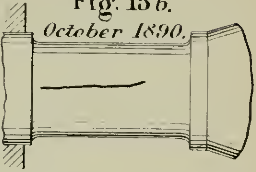


Fig. 15 *c*.

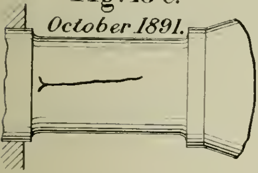


Fig. 15 *d*.

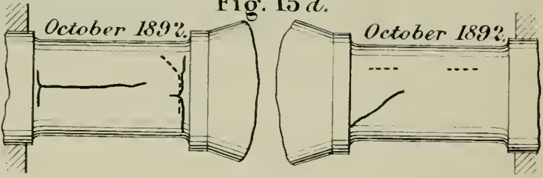


Fig. 16.

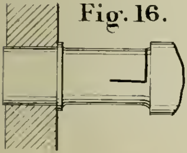


Fig. 17.

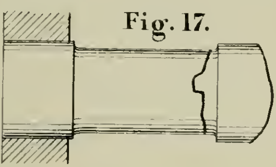


Fig. 18.

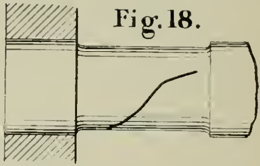


Fig. 19.

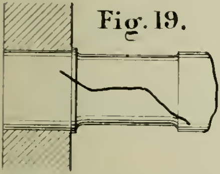


Fig. 20.

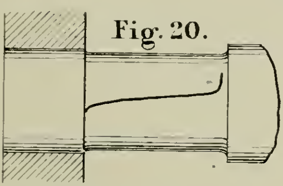
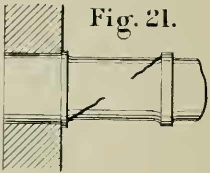


Fig. 21.



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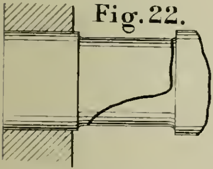

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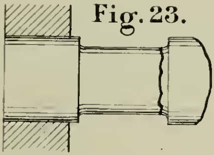

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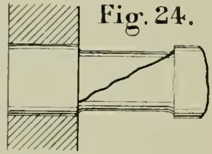

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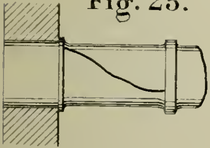
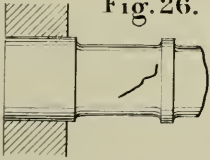


Fig. 26.



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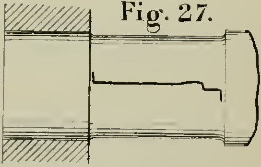

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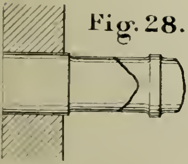

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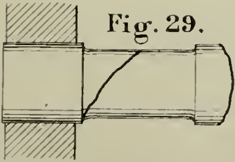

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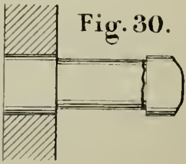

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Main Shafts, 37 Fractured in Neck. Table 9.

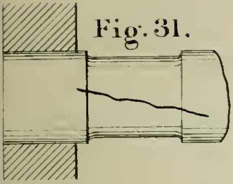


Fig. 31.

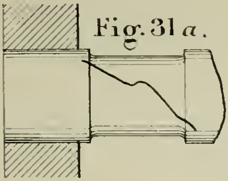


Fig. 31 *a*.

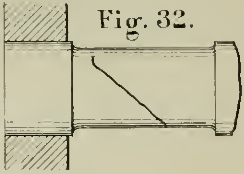


Fig. 32.

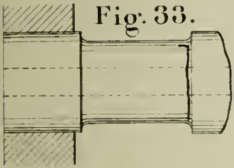
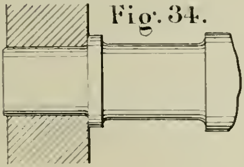


Fig. 33.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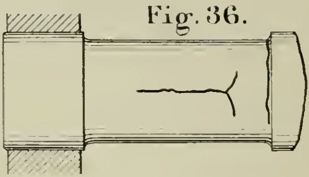
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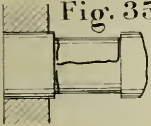
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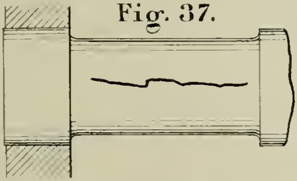


Fig. 37.

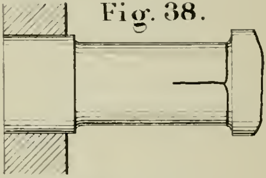


Fig. 38.

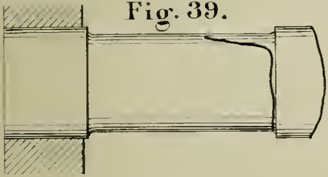
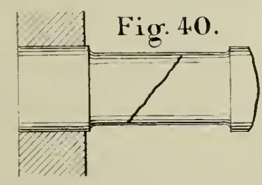


Fig. 39.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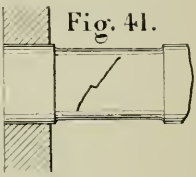
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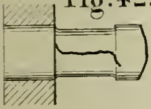
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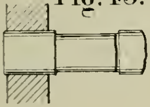
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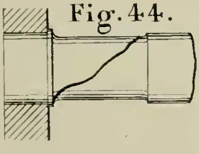


Fig. 44.

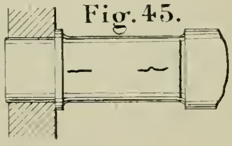
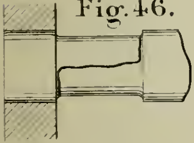


Fig. 45.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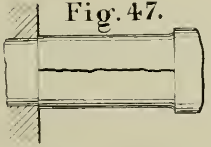
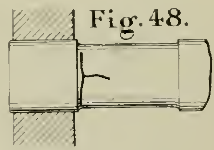


Fig. 47.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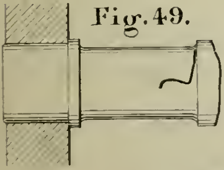


Fig. 49.

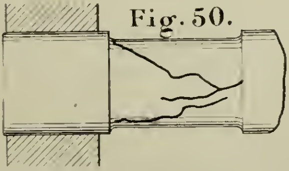


Fig. 50.

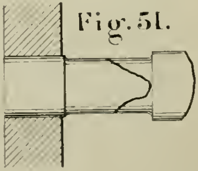
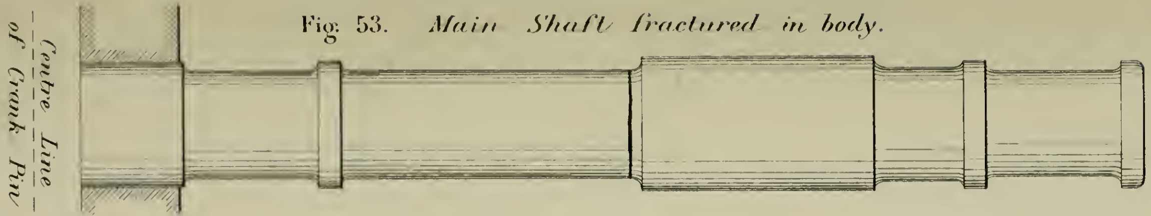


Fig. 51.

STEAM-ENGINE BREAKDOWNS.

Fig: 53. *Main Shaft fractured in body.*



Scale 1/16th

Main Shaft fractured in Body.

Fig: 52.

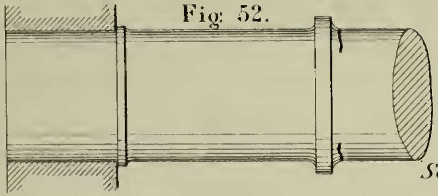
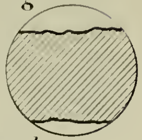
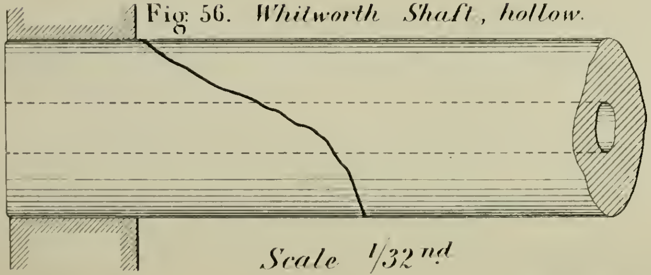


Fig: 52*a*.



Scale 1/32nd

Fig: 56. *Whitworth Shaft, hollow.*



Scale 1/32nd

Main Shaft fractured by Grooving.

Fig: 55*a*.

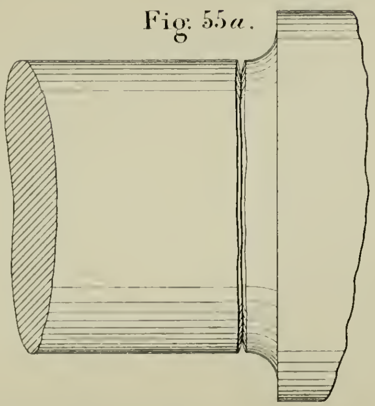
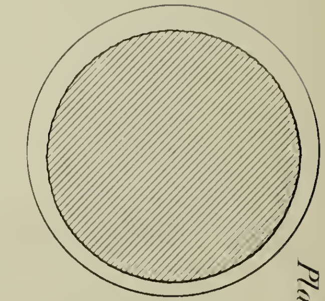


Fig: 55*b*.



Scale 1/8th

Main Shaft fractured in Body.

Scale $^1/_{40}$th.

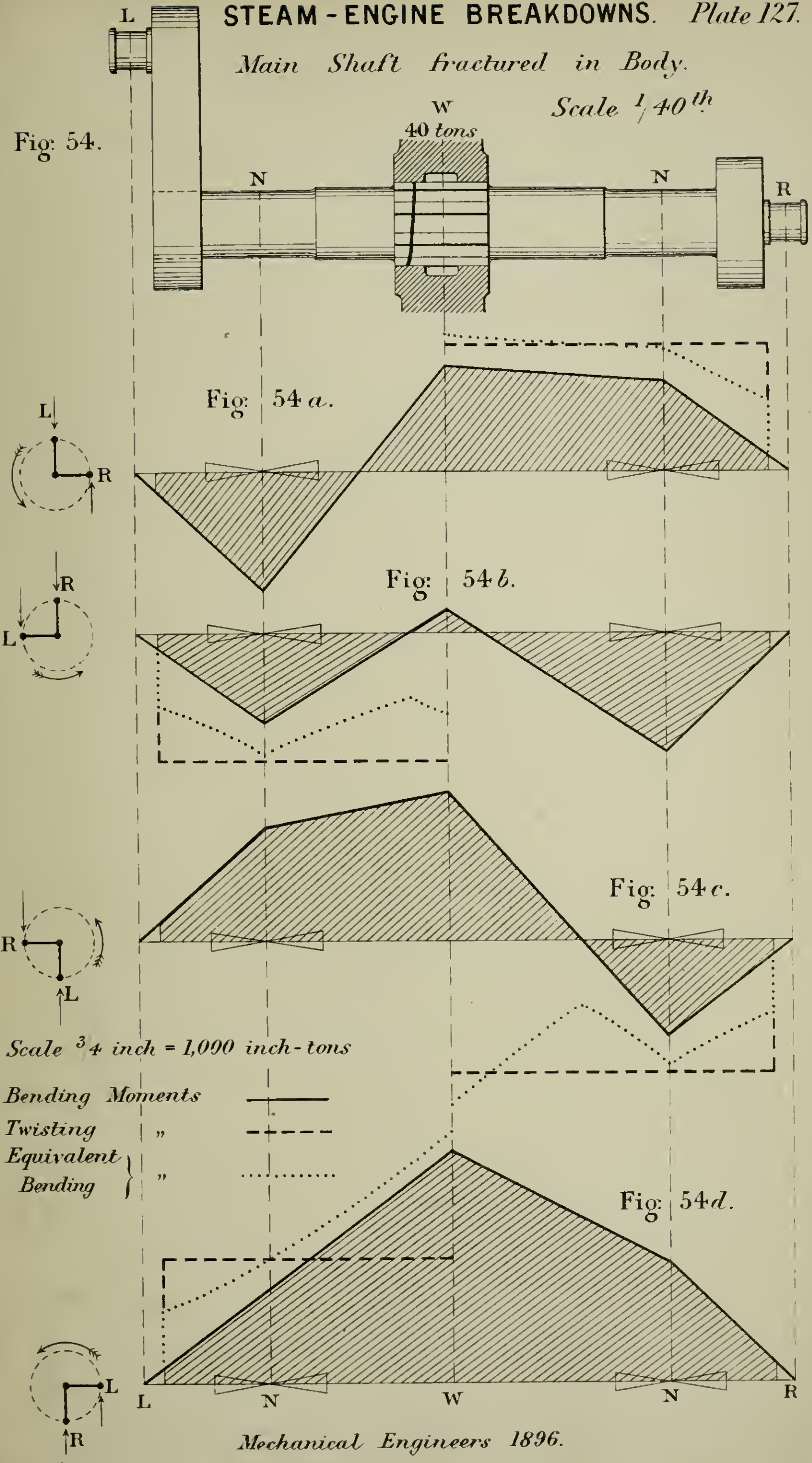


Fig: 54.

Fig: 54 *a*.

Fig: 54 *b*.

Fig: 54 *c*.

Fig: 54 *d*.

Scale ¾ inch = 1,000 inch-tons

Bending Moments ——————

Twisting " – – – – –

Equivalent Bending " ....

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Fig: 55.

Main Shaft W fractured by Grooving.

Scale 1/40th

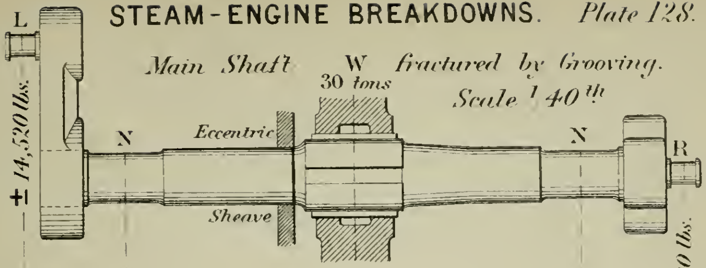


Fig: 55c.

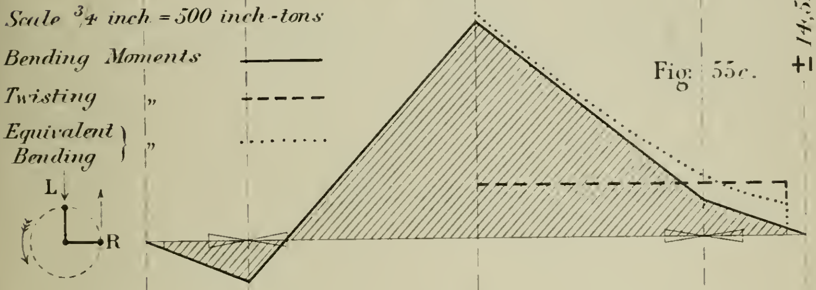


Fig: 55d.

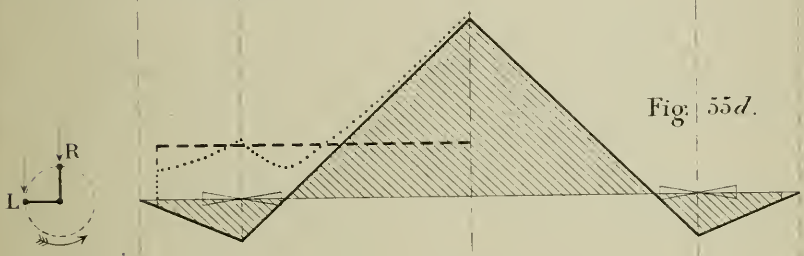


Fig: 55e.

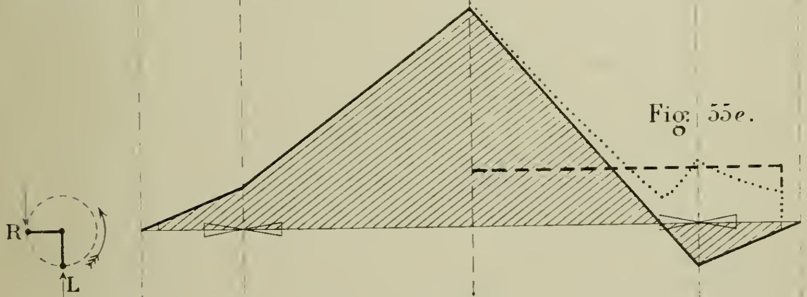
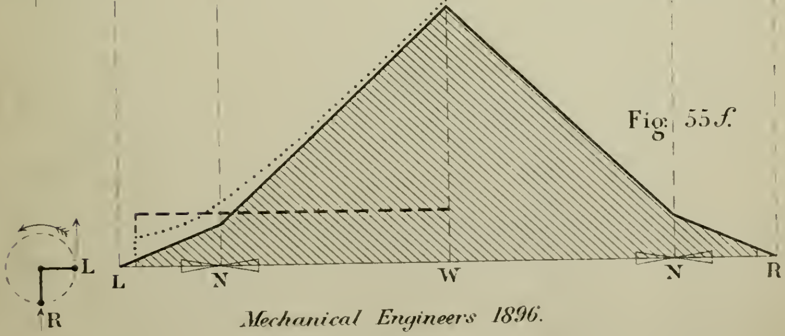


Fig: 55f.



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Piston-Rods, 15 broken at cotter hole in cross-head end. Table 14.

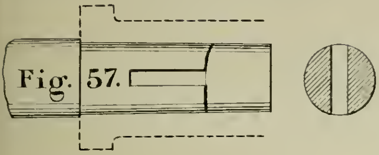
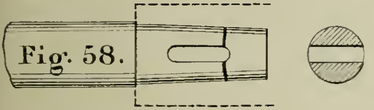


Fig. 57.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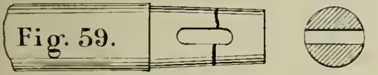
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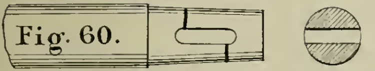
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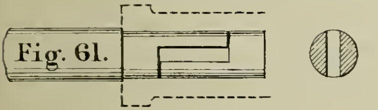
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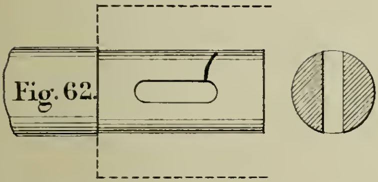
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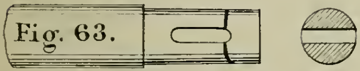
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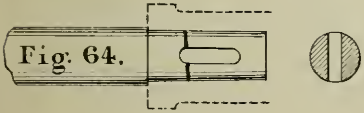
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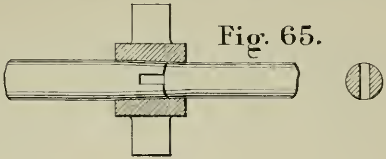
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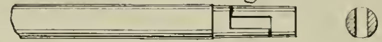
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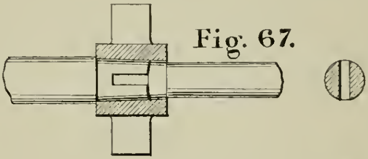
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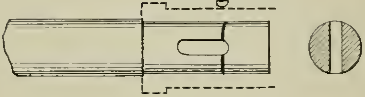
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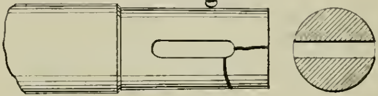
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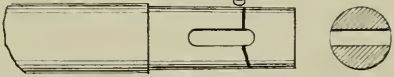
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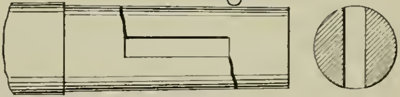
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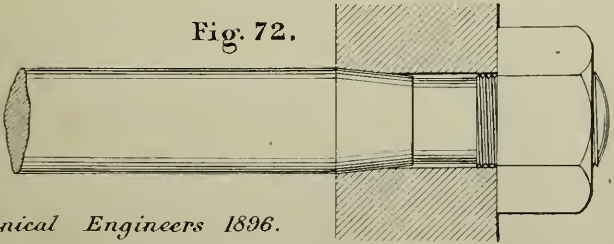
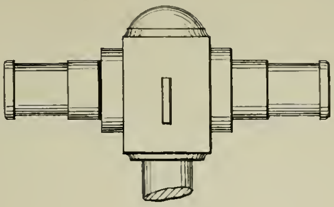
Fig. 72.



Piston-rod Cross-heads. Table 16.



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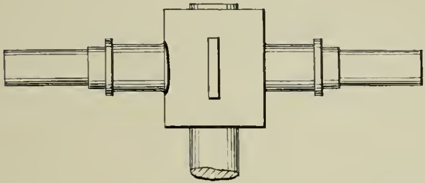

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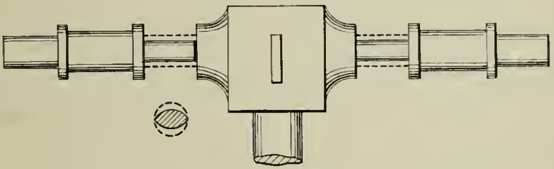

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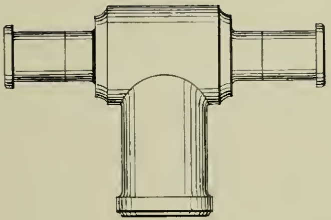

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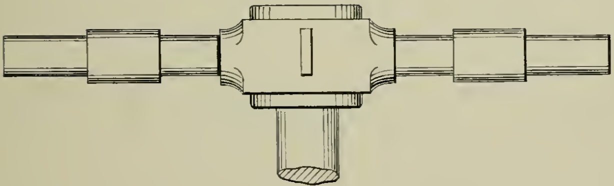

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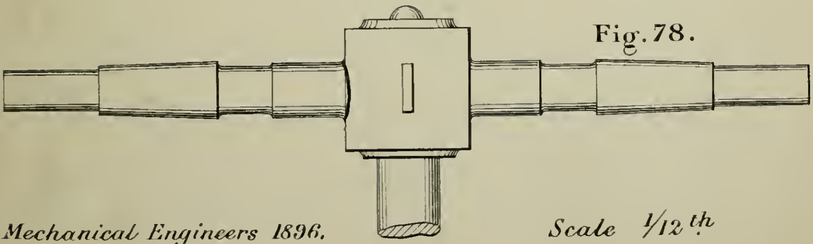
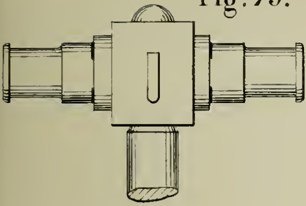


Fig. 78.

Scale 1/12th.

Piston-rod Cross-heads. Table 16.

Fig. 79.



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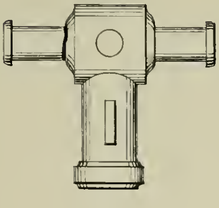

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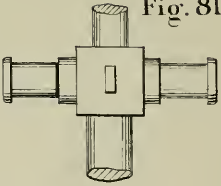

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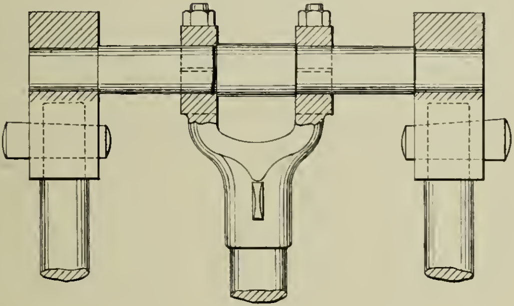

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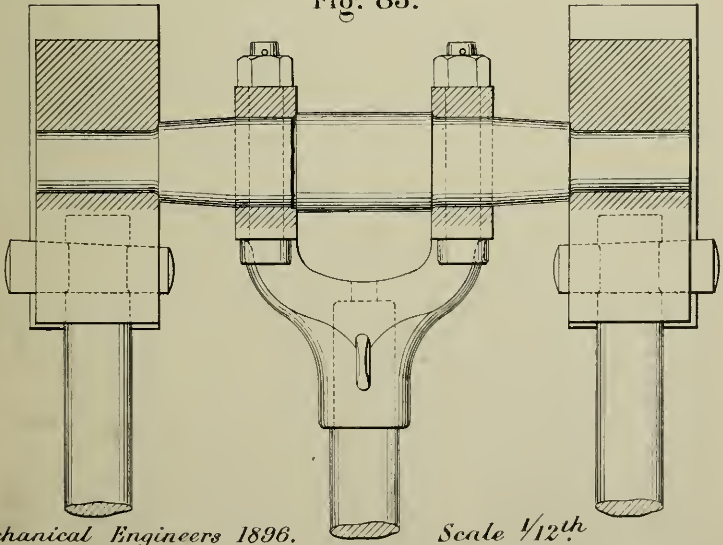
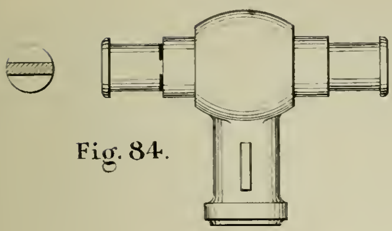


Mechanical Engineers 1896. *Scale 1/12th.*

Piston-rod Cross-heads. Table 16.



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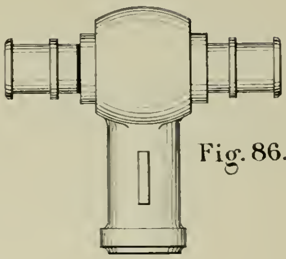
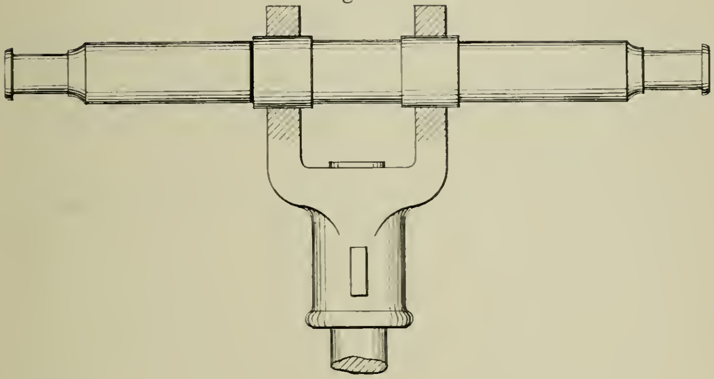


Fig. 86.

Fig. 85.



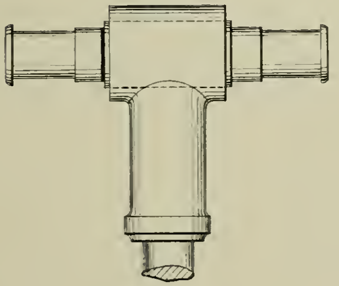
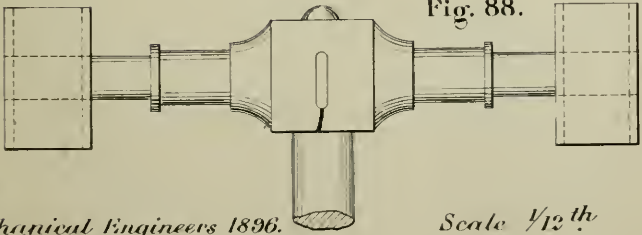


Fig. 87.

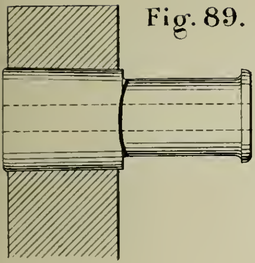
Fig. 88.



Mechanical Engineers 1896.

Scale 1/12th.

Crank-Pins. Table 18.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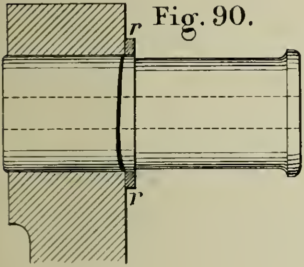
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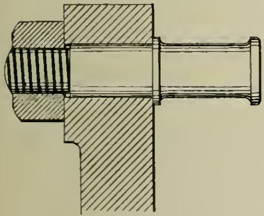
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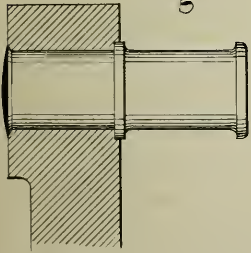
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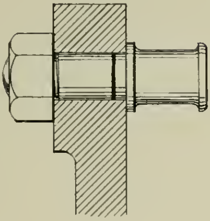
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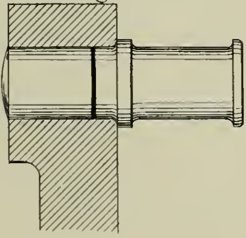
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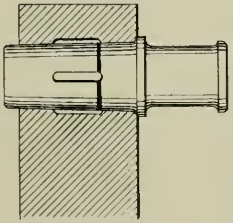
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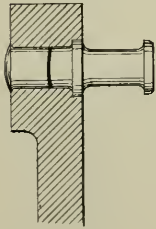
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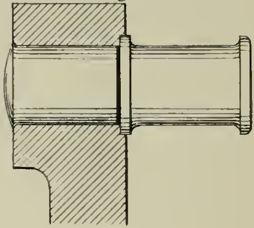
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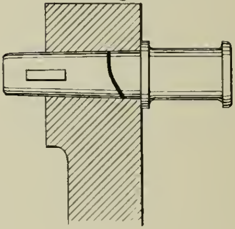
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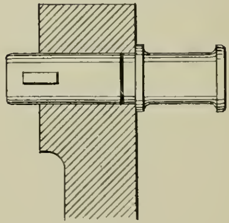
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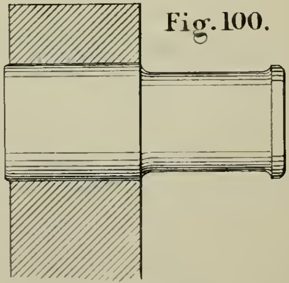


Fig. 100.

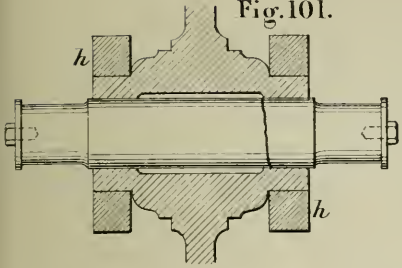
Mechanical Engineers 1896.

Scale 1/12th.

STEAM-ENGINE BREAKDOWNS. *Plate 134.*

Gudgeons in Beams.

Fig. 101.



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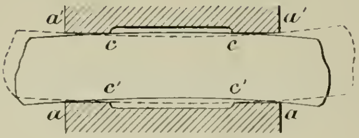

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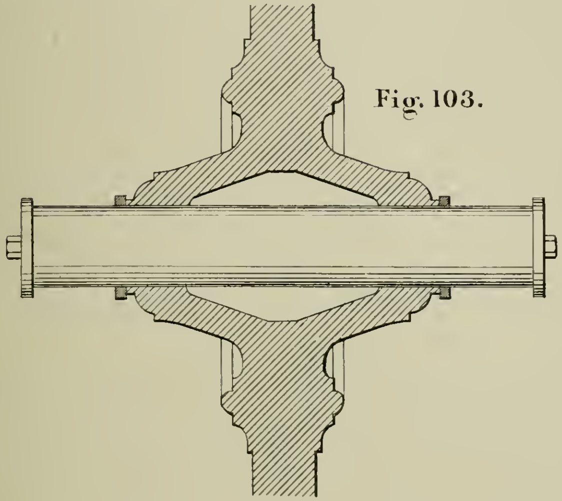

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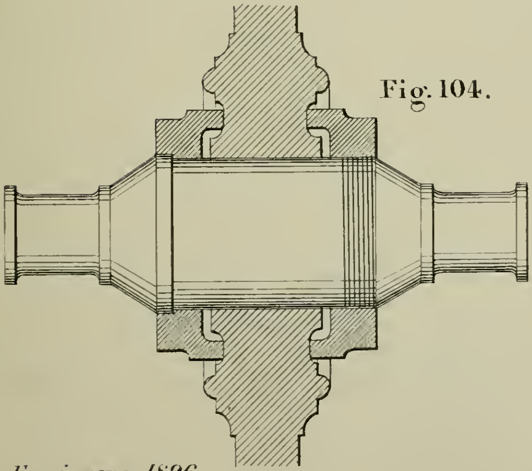


Mechanical Engineers 1896.

Fig: 105. *Curve of Coefficients for Safe Stress, plotted from Wöhler's experiments.*

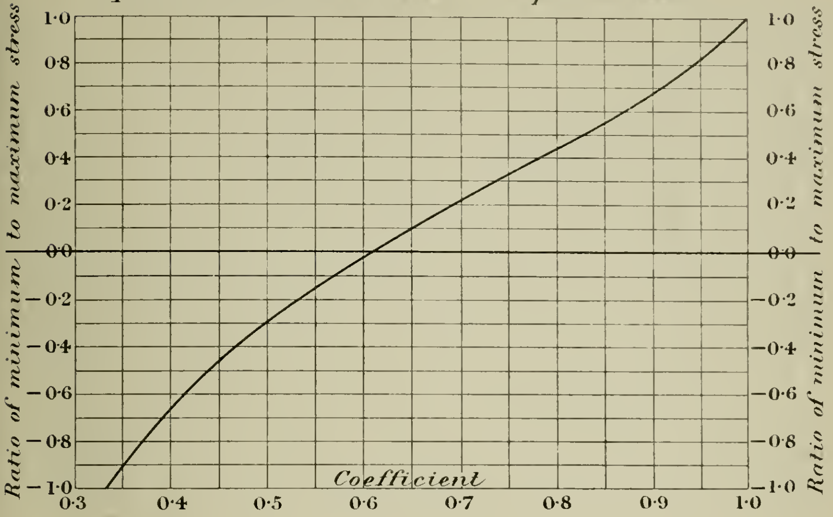
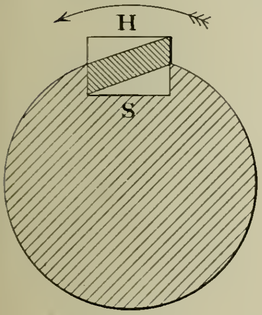
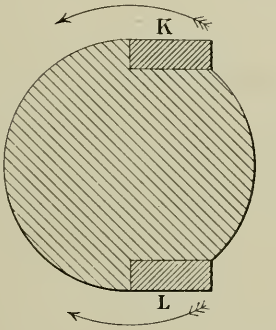


Fig: 106. *Keys.* Fig: 107. *Keys.* Fig: 108.





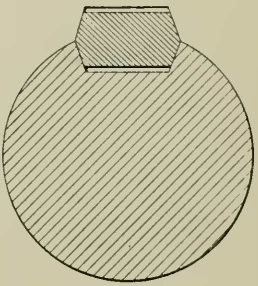
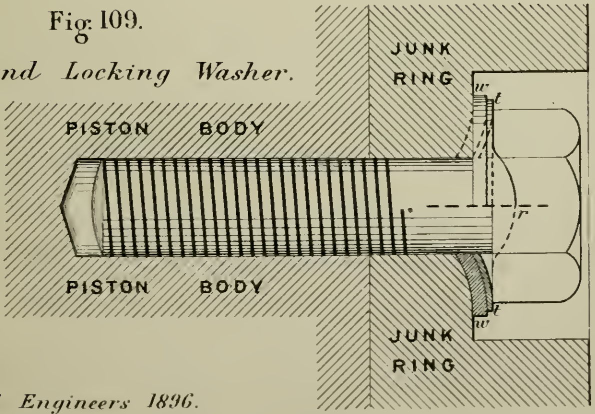


Fig: 109.

Compound Locking Washer.



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